

Astro 210  
Lecture 39  
April 27, 2018

Announcements:

- **HW 11: The Final Frontier posted, due 5:00pm today**  
Congratulations! You are done with HW!
- OBAFGKMLT winners & prizes today!
- Final Exam: May 7, 8:00 am - 11:00 am  
info on Moodle

Last time: our home galaxy—the Milky Way

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

*Q: What's dark matter? what do we know about it?*

# 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*

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

# Changing Gears: Galaxies

## 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

⇒ 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/spheroidal 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

o

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

## Spiral Galaxies

disk stars and gas in circular orbits around center

rotation curve: *orbit speed*  $v_{\text{circ}}(r)$  vs *radius*  $r$

→ in fact, it's easier than measuring our own Galactic rot curve

## Elliptical Galaxies

Stars orbit in all directions → create spheroid shape

∞ in some cases net rotation also found

harder to measure rotation curves to check dark matter

## iClicker Poll: Dark Matter in Other Galaxies

Our Galaxy has a “flat” rotation curve → dark matter  
But what about other galaxies?

Vote your conscience!

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!

Pioneers: Fritz Zwicky, Vera Rubin

Their work and many other showed that

⇒ **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!

# OBAFGKM(LT) Contest Winners