ASTR 1040: Stars & Galaxies

Prof. Juri Toomre TAs: Peri Johnson, Ryan Horton

Lecture 23 Tues 10 Apr 2018

zeus.colorado.edu/astr1040-toomre

Our wide world (universe) of Galaxies

- The rich range of galaxies: *spiral, barred spirals, ellipticals, and irregulars*
- Hubble's scheme to *classify galaxies*
- First look at "expanding universe"
- *Expanding universe:* Hubble's discovery #2
- Finish overview reading *Chap 21 "Galaxy Evolution"*
- Next Tues (Apr 17) class meets in *Fiske Planetarium*
- Next Thur (Apr 19) *Mid-Term Exam 3*

Want to explore teaching as a career?
Interested in STEM Outreach?

*This **Fall 2018** Take…*

Step 1: EDUC 2020 (1 credit)

- Real experience teaching real kids, in Elementary school
- Registration priority for math, science, engineering & open option majors
- Scholarships, fellowships and internships available

CU Teach
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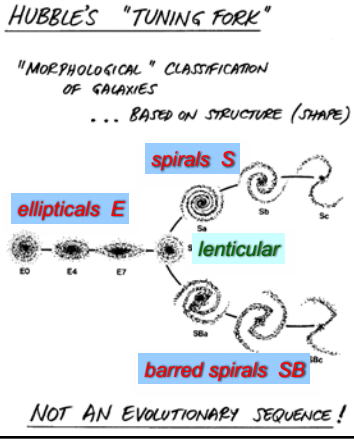
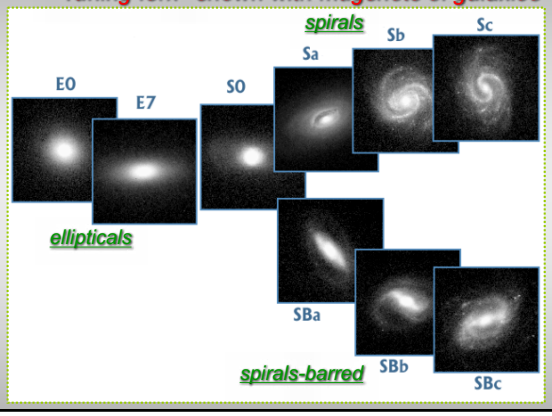
REVISIT

Hubble's scheme to label galaxies

+ some "irregulars"

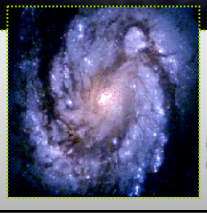


"Tuning fork" shown with mugshots of galaxies

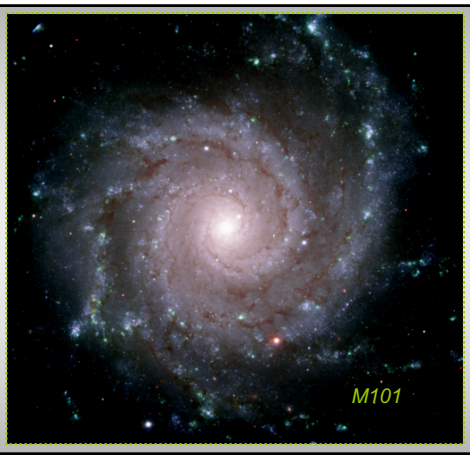


Spirals
~80% of galaxies

- *Disks (with spiral arms) +*
- *Spheroids (bulges+halos)*

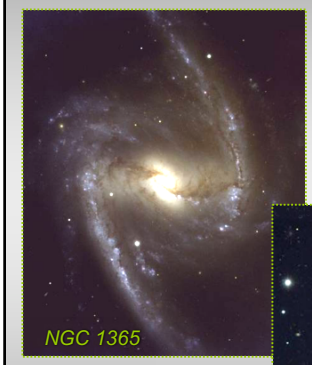


M100 center



Barred spiral galaxies

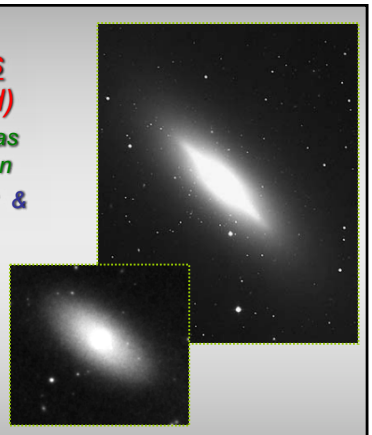
- Spiral arms emerge from central bar



HST: Center of barred spiral NGC 1365

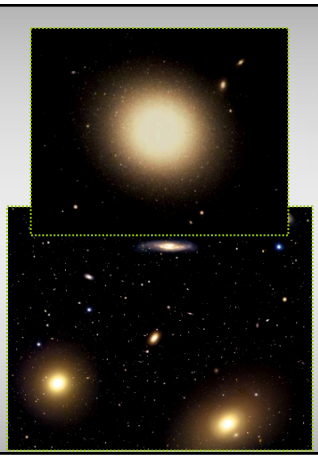
Lenticulars (lens-shaped)

- Disks, but less gas and star formation
- Note lack of dust & pink nebulae



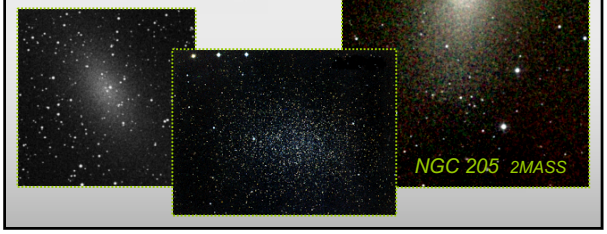
Ellipticals ~15% of galaxies

- Round or slightly flattened
- Very little cold gas, dust, or young stars
- Reddish color = old stars (red giants, red main sequence)



Dwarf ellipticals

- Most common type of galaxy?
- Only know nearby ones (since faint !)



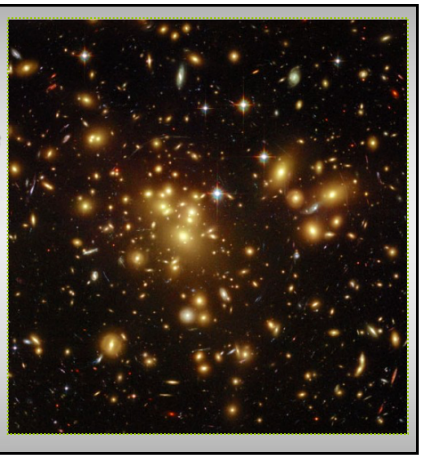
Irregulars

- Galaxies in transformation? Often LOTS of star birth

Where do spirals and ellipticals live?

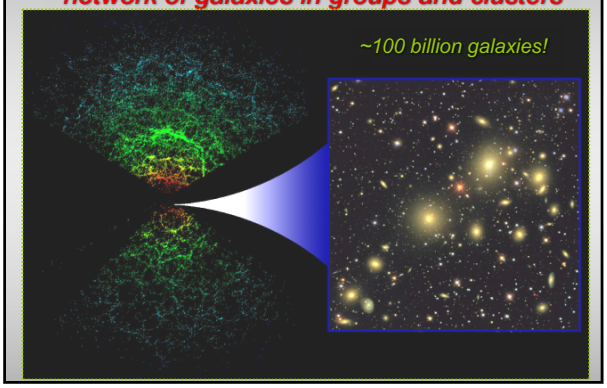
- Spirals – mostly in groups (3-10 galaxies)

- Ellipticals - most often in dense clusters of galaxies (involve 100's to 1000's)
- Often a few massive "CD" galaxies near center

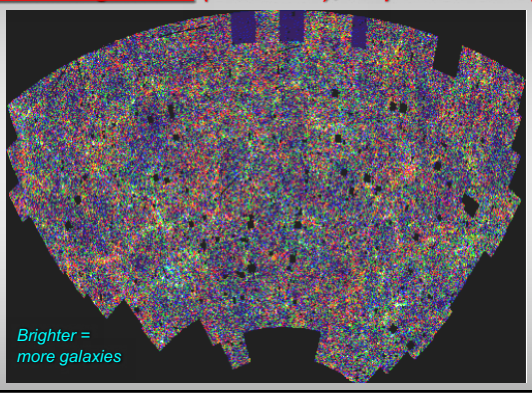


HST: Abell 1689

The Big Picture: Universe is filled with network of galaxies in groups and clusters

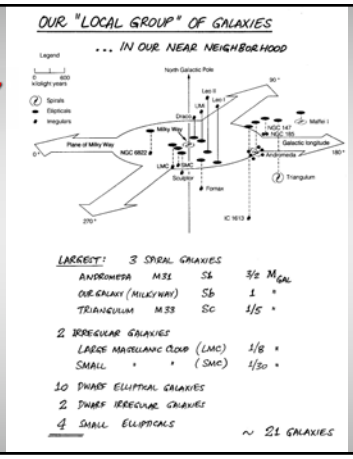


Pattern of galaxies (3 million+), 15° portion of sky



Our "local group" of galaxies

3 spirals:
Andromeda (M31)
Milky Way
Triangulum (M33)
2 irregulars:
LMC
SMC
16+ dwarfs



Biggest is Andromeda (Sb - M31)

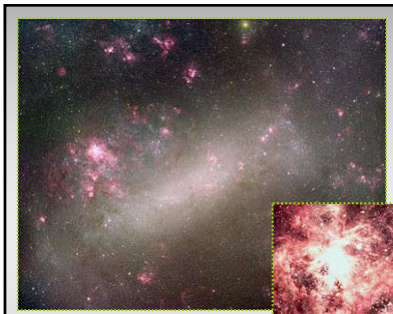
- Andromeda is ~2.5 million light years away (780 kpc) (or ~35 MW diameters), has ~1.5 mass of MW
- We see her as "she" was 2.54 million years ago, not as she is today! – this is lookback time
- Oops! she may crash into MW in about 2+ billion years

Andromeda: in IR + Xray views

Triangulum (M33)

- 1/5 mass of MW, spiral classified as Sc
- Several bright (pink) star forming regions

Large & Small Magellanic Clouds



LMC has 30 Doradus, home of SN 1987A

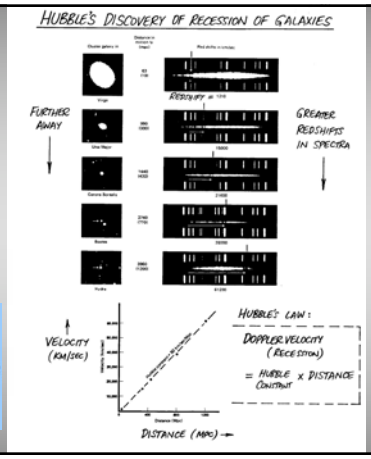
Hubble: next showed universe appeared to be expanding!

- Vesto Slipher (1912) reported that most galaxies showed Doppler redshifts
- Edwin Hubble, using new 100" telescope, started busily measuring galaxy redshifts
- Hubble (1929) announced that redshifts of galaxies appear to increase with distance from us
- This was startling: suggests an EXPANDING UNIVERSE !

Hubble and recession of galaxies: measured many redshifts

Further away, greater redshift !

Hubble guessed their distances by size and brightness -- underestimated by factor 10!

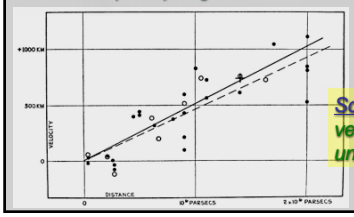


Hubble showed universe appears to be expanding!

Hubble's Law: $v = H_o\ d$

- v: Velocity of Recession (Doppler Shift) (km/sec)
- H_o: Hubble's Constant (km/sec/Mpc)
- d: Distance (Mpc)

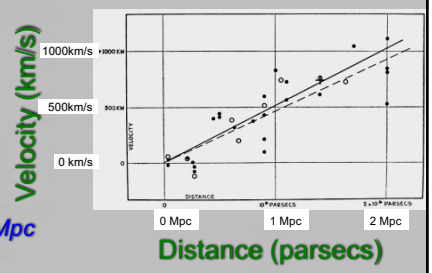
Hubble's (1929) original:



Scatter here from random velocities of nearby galaxies, unreliable distance estimates

Clicker Question

From Hubble's original plot, what is the Hubble Constant?

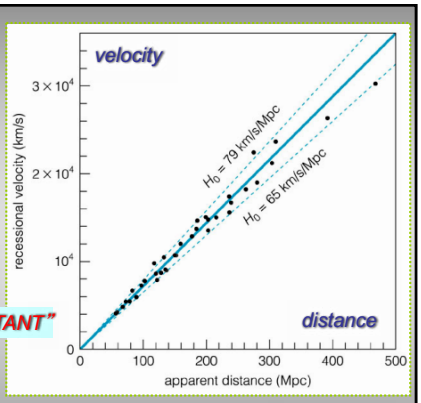


A. 100 km/s
B. 500 km/s
C. 500 km/s/Mpc
D. 1000 km/s
E. 1000 km/s/Mpc

Best current values for expansion

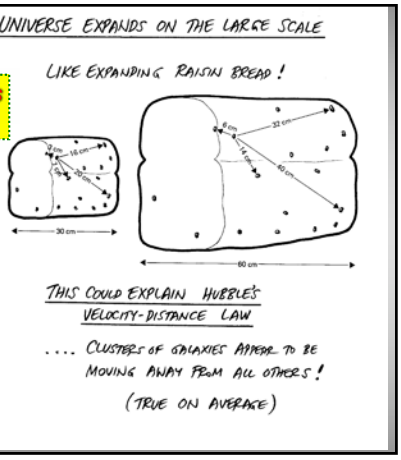
H_o = **71 +/- 4 km/s/Mpc**

"HUBBLE CONSTANT"



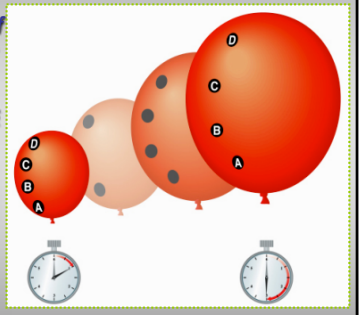
Hubble (1929) plot extended only to 2 Mpc, H_o was ~500 !

Universe expands like raisin bread !



Balloon analogy for expanding universe

- On an expanding balloon, no galaxy is at the "center" of expansion; no edge
- Expansion happens into a higher dimension (2-D surface into a 3-D space)
- Is our 3-D space expanding through a 4th dimension?



Clicker -- reading on galaxies

- How might you classify this galaxy?

- A. Sa
- B. SBb
- C. E
- D. SO

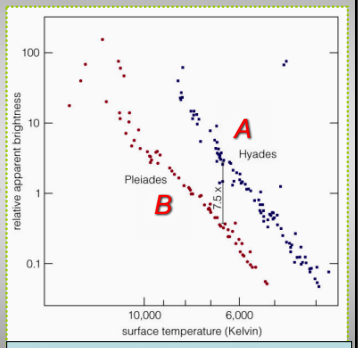
Mapping the universe: need distances to galaxies!

- Identify (and calibrate) properties of galaxies that could serve as "STANDARD CANDLES" -- beyond direct measure by trigonometric parallax
- 1. Make some measure of an object which identifies its luminosity (like period in Cepheid)
- 2. Use this luminosity and measure apparent brightness to infer distance to it

Main-Sequence Fitting

DISTANCE ESTIMATE 1

- Start with cluster A (upper) whose distance known via parallax
- Compare with other cluster B (lower)
- Get distance to B from brightness difference



Distances up to ~200,000 light years

Main Sequence Fitting often compared to nearby Hyades Cluster (M45)

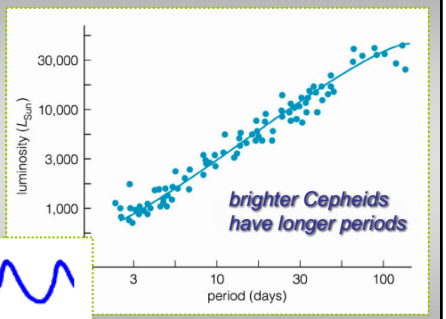
Only 151 ly away

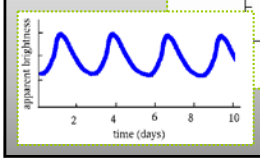
Close enough to get distance estimate through parallax

Cepheid variable stars

DISTANCE ESTIMATE 2

Period - Luminosity relation

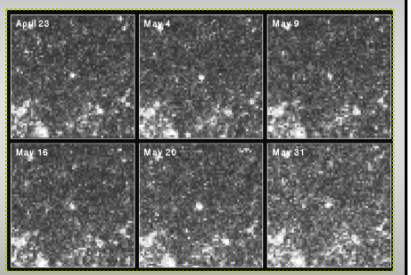




Cepheids variables as standard candles

DISTANCE ESTIMATE 2

1. Measure period of variability
2. From period-luminosity relation, infer the luminosity
3. Compare with apparent brightness and thus determine distance

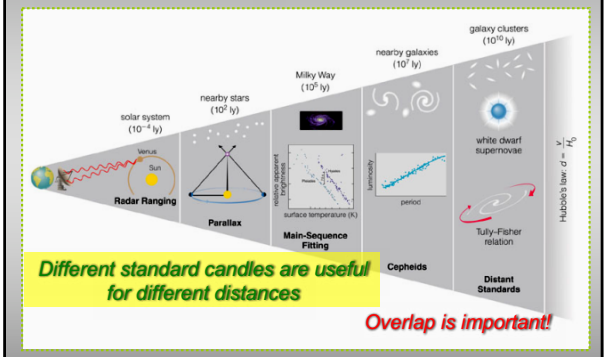


Cepheid variable in M100 (HST)

Number of Fuzzier Distance Estimators

- A. Apparent brightness of (resolved) red and blue supergiants
- B. Size and brightness of H II regions (emission nebulae) or starbirth regions
- C. Intercompare distances so deduced for specific galaxies (overlapping rungs in `distance ladder')

Distance ladder to measure universe



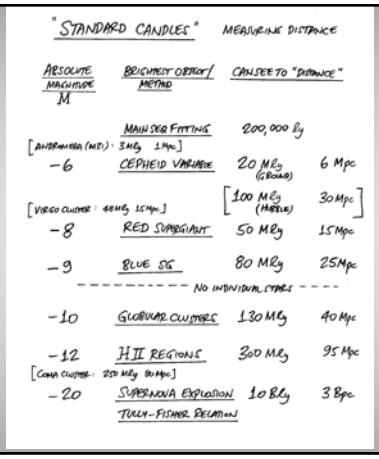
Different standard candles are useful for different distances

Overlap is important!

"Distance ladder"

Overlapping "standard candles"

DEMO



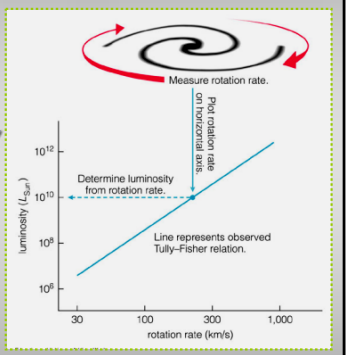
Tully-Fisher Relation

DISTANCE ESTIMATE 3

- Fast rotation speeds in spiral galaxies
- → more mass in galaxy
- → higher luminosity

Measure rotation speeds to infer luminosity

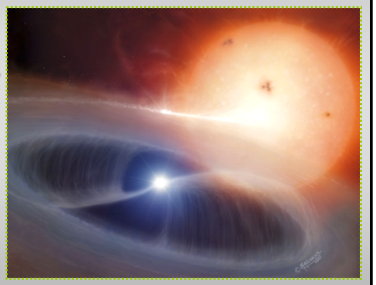
Need bright "edge-on" spirals, estimate tilt



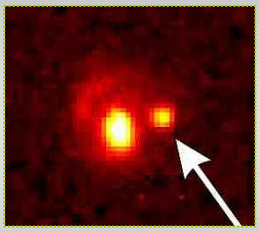
DISTANCE ESTIMATE 4

Even brighter: White dwarf supernovae

- "Standard explosion" = fusion of 1.4 solar masses of material
- Nearly the same amount of energy released

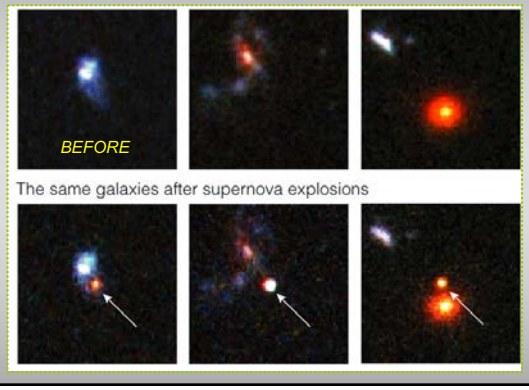


Bright enough to be seen halfway across observable universe



Useful for mapping the universe to the largest distances

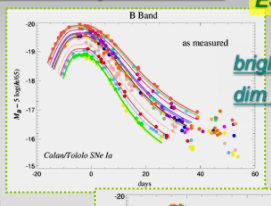
Supernovae in very distant galaxies



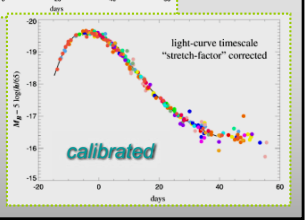
White dwarf supernovae

DISTANCE ESTIMATE 4

- Carbon fusion explosion: mass transfer in binary takes white dwarf `over the edge'
- Roughly same amount of energy released (calibrate)



brighter SN
dim more slowly!



Measuring big distances to galaxies

"STANDARD CANDLES" -- important ones in `distance ladder'

- 0. Parallax
- 1. Main-sequence fitting
- 2. Cepheid variables
- 3. Tully-Fisher relation
- 4. White dwarf supernovae

Brightness ~ Luminosity / (Distance)^2