ASTR 1120: Stars & Galaxies

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Lecture 33 Mon 4 Apr 05

zeus.colorado.edu/astr1120-toomre

Today's Topics

- How we *measure big distances* -- and what an *expanding universe* means
- *Planetarium #3 this Wed 6 April* – Dick McCray presents `*SUPERNOVAE*' – go there directly
- *Observatory Night # 7 this Wed* 8:30pm+ signup
- Overview read *Chap 21 Galaxy Evolution* for Friday lecture, plus *21.5 Quasars* in detail
- *Homework Set 8* on *Cosmic Distances and Hubble Law* due today
- *New Homework Set 9 PLANET FINDER still available: team format, all Web / Java based*
- *HELP LABS this Tues, Wed, Thurs 4-6m, plus Thurs 7-9pm – get started now, if not already*

Clicker: halo stars *C.*

- *Massive O-type stars are not found in the galactic halo because they are:*

A. too massive to be kicked into the halo from the disk

B. so massive that they settle into the thinner disk

C. too short-lived to have persisted from halo formation until today

D. too far away for us to see them

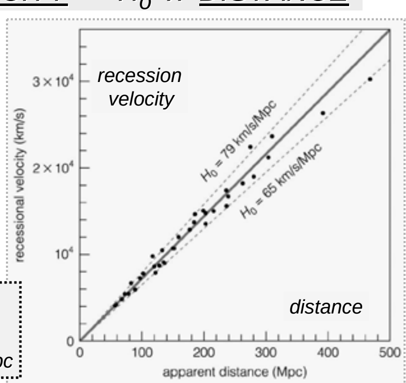
Why no O-stars?

- C. *Too short lived to be in the halo*

Halo stars were born billions of years ago; the most massive stars don't live nearly that long

Will have disappeared by now (after having "enriched" the proto-galaxy gas with heavy elements)

VELOCITY = H_o x DISTANCE



"HUBBLE CONSTANT"

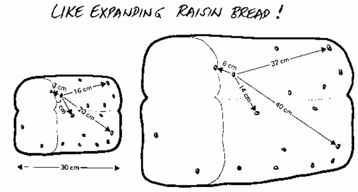
H_o = 71 +/- 4 km / sec / Mpc

UNIVERSE EXPANDS ON THE LARGE SCALE

Hubble's Law implies:

Universe expands like raisin bread !

LIKE EXPANDING RAISIN BREAD !



THIS COULD EXPLAIN HUBBLE'S VELOCITY-DISTANCE LAW

True for very large scales between galaxies – but not for stars, planets, us!

.... CLUSTERS OF GALAXIES APPEAR TO BE MOVING AWAY FROM ALL OTHERS !

(TRUE ON AVERAGE)

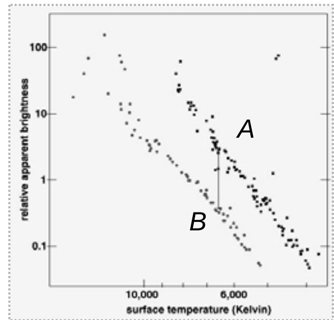
Mapping the universe: need distances to galaxies!

- *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*

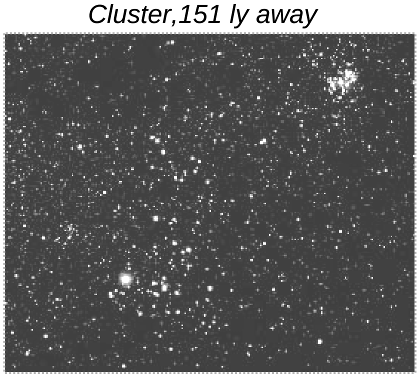
Main-Sequence Fitting

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*



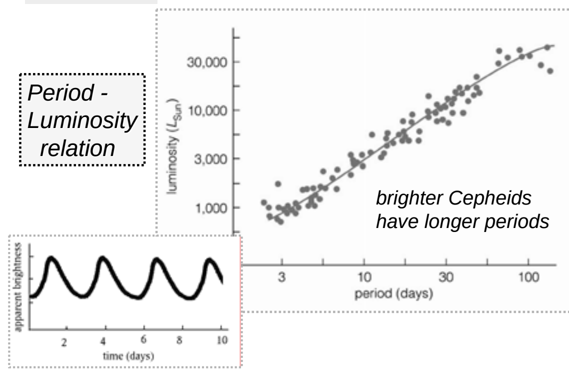
M-S Fitting "pinned to" nearby Hyades Cluster,151 ly away



Cepheid variable stars

DISTANCE ESTIMATE 2

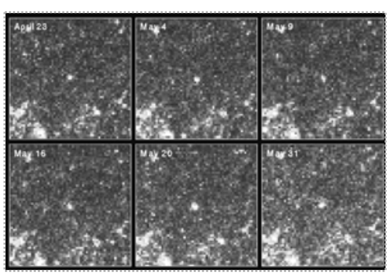
Period - Luminosity relation



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)

Clicker – Cepheids and distance

- *Two Cepheid stars, Fred and Barney, have the same apparent brightness. Fred has a period of 5 days, and Barney of 10 days. Which is closer ?*

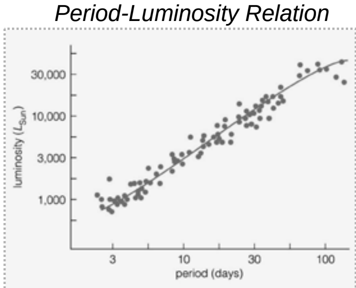
- *A.* Fred
- *B.* Barney

A.

Why A. Fred ?

- Fred has a shorter period and so must be less luminous
- Less luminous but the same apparent brightness means that Fred is closer to us

Period-Luminosity Relation



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')

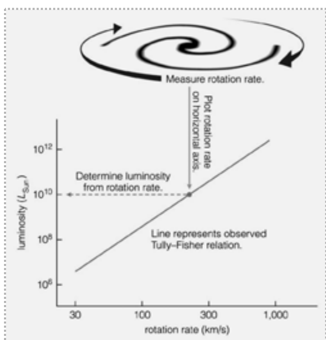
DISTANCE ESTIMATE 3

Tully-Fisher Relation

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

Measure rotation speeds to infer luminosity

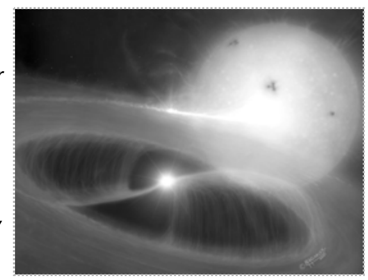
Need bright "edge-on" spirals, estimate tilt



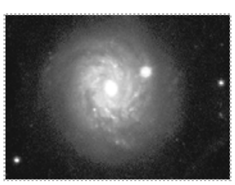
DISTANCE ESTIMATE 4

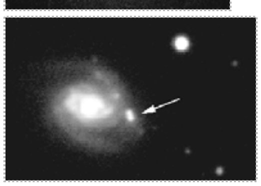
Even brighter: White dwarf supernovae

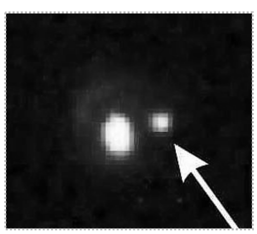
- "Standard explosion" = fusion of 1.4 solar masses of material
- Nearly the same amount of energy released



Bright enough to be seen halfway across observable universe



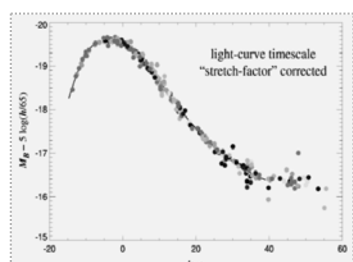




Useful for mapping the universe to the largest distances

Practical difficulty: White dwarf SN

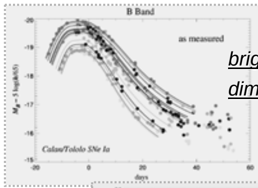
- Need to catch them within a day or two of the explosion
- About 1 per galaxy per century
- Need to monitor thousands of galaxies to catch a few per year → galaxy clusters are useful



DISTANCE ESTIMATE 4

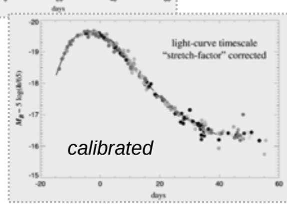
White dwarf supernovae

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

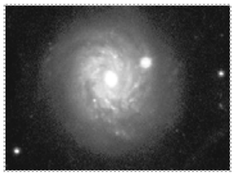


brighter SN

dim more slowly!



calibrated



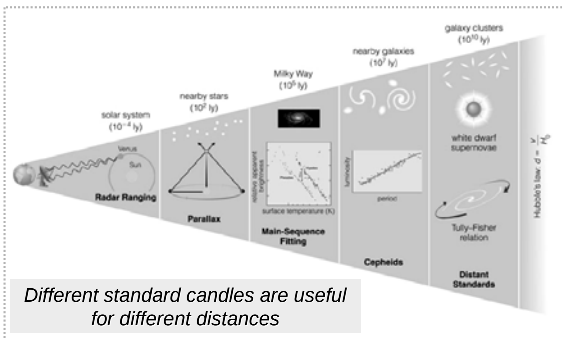
“Distance ladder”

Overlapping “standard candles”

"STANDARD CANDLES" MEASURING DISTANCE

ABSOLUTE MAGNITUDE M	BRIGHTEST OBJECT/ METHOD	CAN SEE TO "DISTANCE"	
	MAIN SEQ FITTING	200,000 ly	
[ANDROMEDA (M31): 3 Mly 1 Mpc]			
−6	CEPHEID VARIABLE	20 Mly (GROUND)	6 Mpc
		[100 Mly (HUBBLE)	30 Mpc]
[VIRGO CLUSTER: 48 Mly 15 Mpc]			
−8	RED SUPERGIANT	50 Mly	15 Mpc
−9	BLUE SG	80 Mly	25 Mpc
	----- NO INDIVIDUAL STARS -----		
−10	GLOBULAR CLUSTERS	130 Mly	40 Mpc
−12	H II REGIONS	300 Mly	95 Mpc
[COMA CLUSTER: 250 Mly 80 Mpc]			
−20	SUPERNOVA EXPLOSION	10 Bly	3 Bpc
	TULLY-FISHER RELATION		

Distance ladder to measure universe



Different standard candles are useful for different distances

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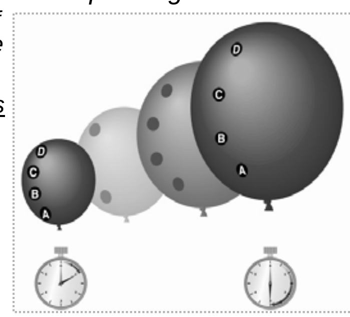
Balloon analogy for expanding universe

- 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?



Measuring big distances to galaxies

“STANDARD CANDLES” -- important ones in `distance ladder’, or `chain’

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

Brightness ~ Luminosity / $(\text{Distance})^2$

DISTANCE ESTIMATE 5

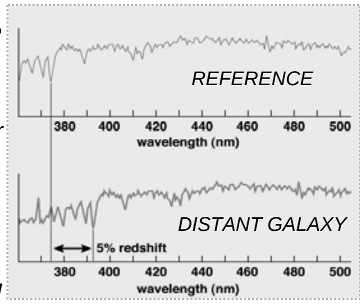
Use Hubble’s Law itself to estimate vast distances D

- Measure velocity, then: $D = v / H_o$
- Example: using H_o = 70 km/sec/Mpc, and finding that v = 700 km/sec

D = 700 km/sec / 70 km/sec/Mpc = 10 Mpc
= 32 million light years

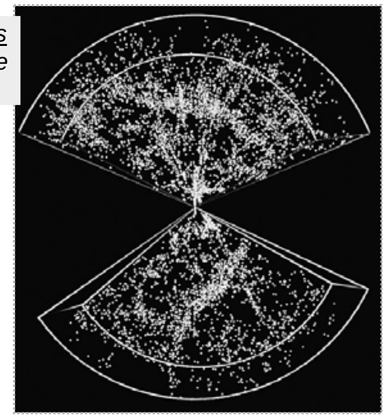
Use Hubble's Law for "distances"

- *Measuring distances to remote galaxies is difficult, but measuring Doppler shifts (velocities) is easier from spectra*
- *Use Hubble's Law to estimate biggest distances (really LOOKBACK TIME)!*

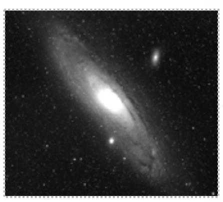


Knowing distances reveals large-scale galaxy clustering

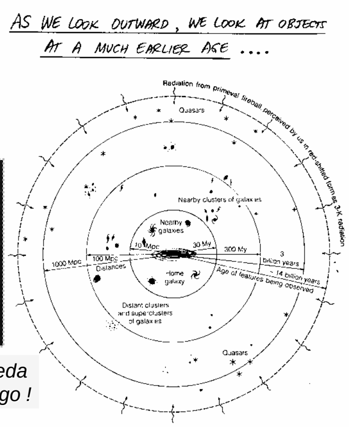
Find clusters + super-clusters : sheets and voids like `bubble bath'



Telescopes are "lookback" time machines

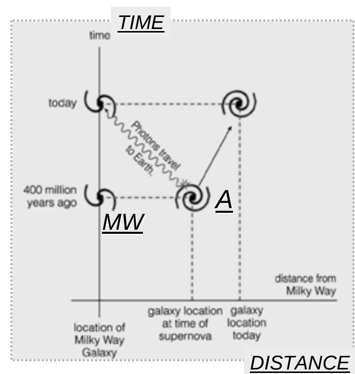


Today, we see Andromeda as she was 3 M years ago !



Lookback time (in expanding universe)

- *Say it takes 400 million years for light to get from galaxy A to us in Milky Way*
- *Yet during travel in spacetime, both A and MW have changed positions by expansion*
- *Thus "distance" is a fuzzy concept – LOOKBACK TIME is better*



Next class: Wed 6 April

Go directly to Fiske Planetarium

Dick McCray: SUPERNOVAE

Also -- Observatory Night # 7 on Wed