ASTRO 330 - Galaxies
Class 2 Exercise: Jan 27, 2025
Redshifts and Hubble's Law

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1. a) Explain how cosmic expansion produces the signature that galaxies' apparent radial speed increases proportionally to their distance from us (Hubble's Law). You can give a qualitative explanation or use an analogy.

b) If we limit our observations to nearby galaxies (as was the case for the first several decades studying this phenomenon), is Hubble's Law consistent with a constant expansion rate?

Cosmic exponsion is stated by the Hubble's law. It says that the apparent radial
a) velocity of a galaxy (v) increases proportionally with distance (d) from us: $v = H_0 d$
H_0 = Hubble constant. Imagine placing paper clips at equal intervals along a stretched rubber band. Each clip represents a Galaxy. If you stretch the rubber evenly in all directions, the distance between each pair of clips increases. A paper clips farthest away from a reference point (your thumb) moves a greater absolute distance when the band is stretched. Since movement is proportional to original spacing, the farther a clip is, the faster it moves away from the reference point.

b) Limiting our observations, ~~so~~ Hubble's law would still appear consistent with a constant expansion rate. But this is because at small distances, effects of cosmic acceleration are not as noticeable.

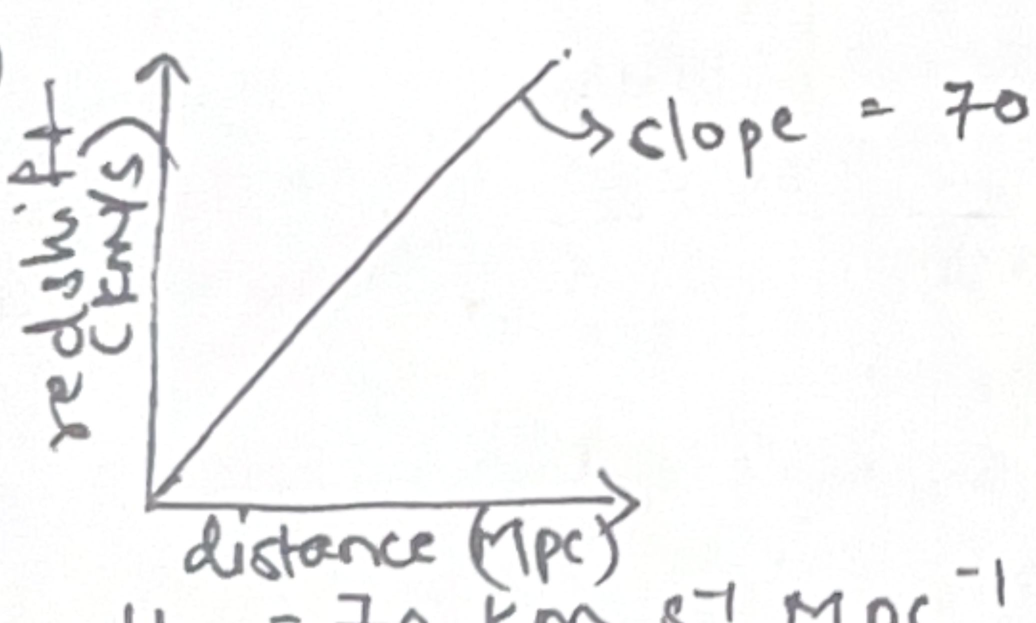
2. a) If the Hubble constant were 50 km s^{-1} Mpc^{-1} instead of $H_0 = 70$ km s^{-1} Mpc^{-1}, would the Universe be expanding more slowly or more quickly?

b) Sketch and label Hubble plots (velocity vs distance) for these two Universes. (You can do this schematically - no need to include numbers.)

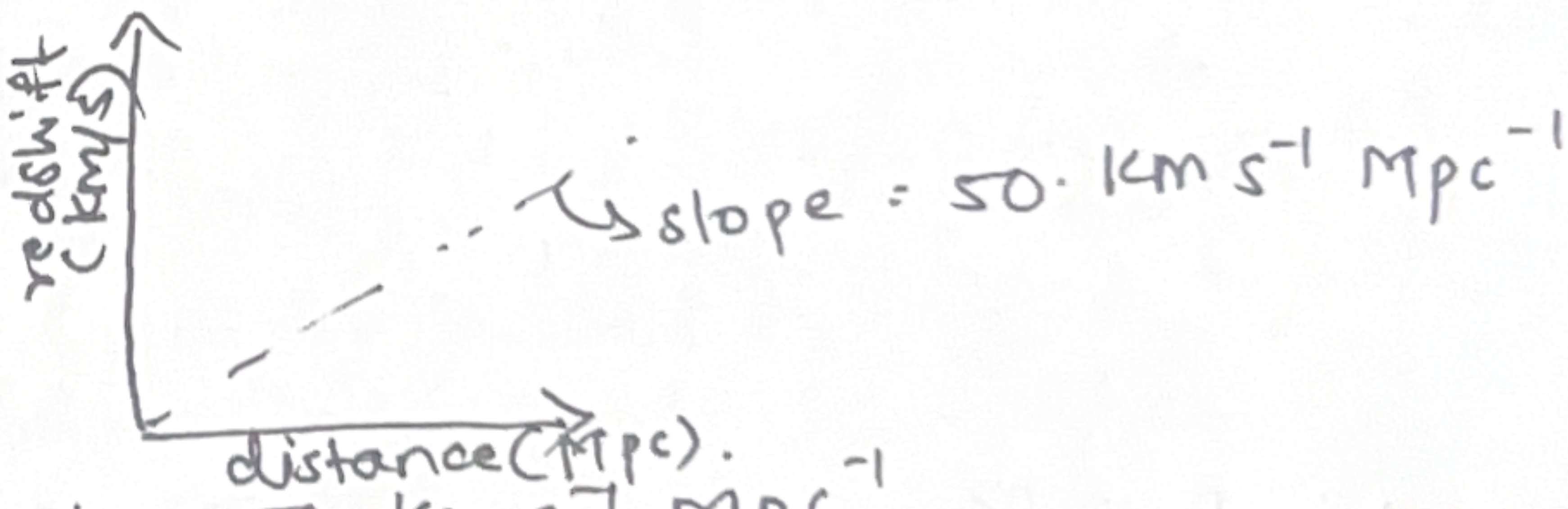
c) Sketch a Hubble plot for a Universe that is in a steady state (neither expanding or contracting).

a) If the Hubble constant were 50 km s^{-1} Mpc^{-1}, the Universe would be expanding more slowly.

b)

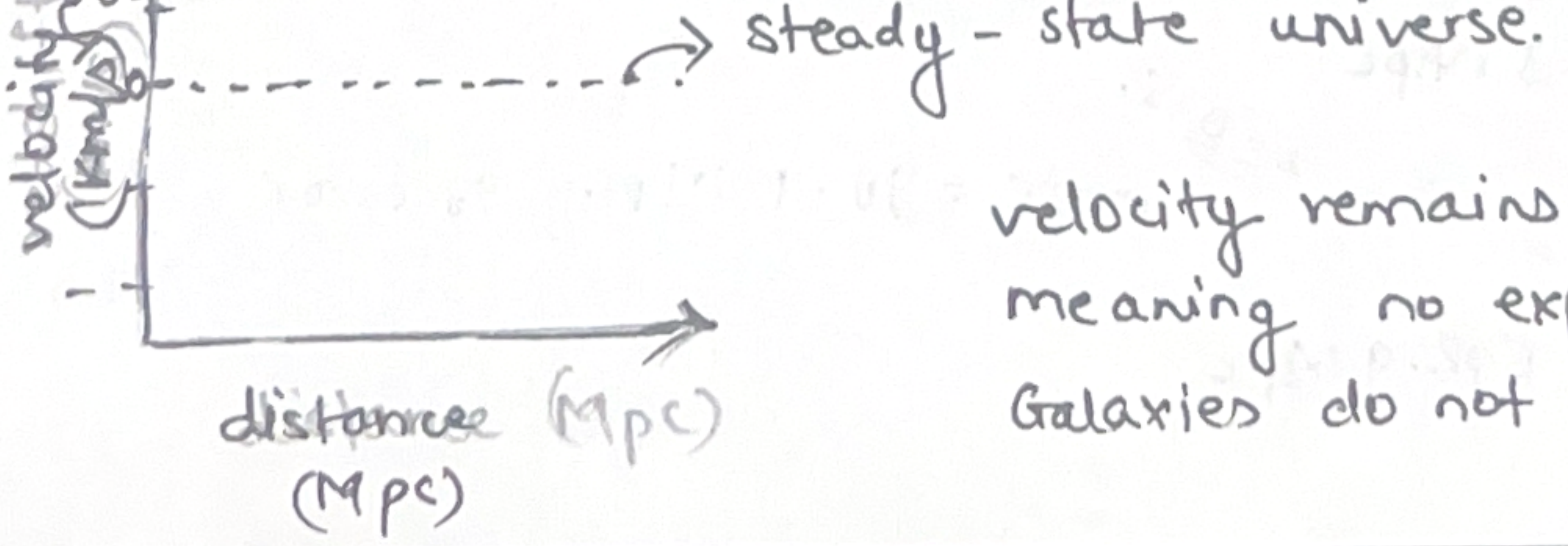


H_0 = 70 km s^{-1} Mpc^{-1}



H_0 = 50 km s^{-1} Mpc^{-1}

c)



velocity remains zero for all distances meaning no expansion/ contraction. Galaxies do not move relative to each other.

3. In the late 1990s brightness measurements of Type Ia supernovae at redshifts > 0.3 provided strong observational evidence that today's expansion rate is faster than it has been for much of the Universe's history (the Universe's expansion is accelerating). Do we observe a larger rate of expansion at low redshift or high redshift?

Larger rate of expansion at lower redshift.

$z > 0.3$ (High redshift) - represents early universe, where expansion was slower.

$z < 0.3$ (low redshift) - represents more recent universe where expansion has accelerated.

4. You observe a Type Ia supernova in a distant galaxy. The supernova is a standard candle: by measuring how fast its brightness fades over a few weeks, you can determine its absolute luminosity to high accuracy. The actual distance you measure from the supernova's luminosity and brightness is D_{SN}. Separately, you measure the galaxy's redshift to be $z = 0.79$. If you plug this redshift into Hubble's Law and assume a constant expansion rate H_0 over the history of the Universe, you get a predicted distance D_{H0}. **Given the actual change in the cosmic expansion rate over time, will you find $D_{SN} > D_{H0}$ or $D_{SN} < D_{H0}$? Explain.**

$D_{SN} > D_{H_0}$.

→ Hubble's Law and assumptions of constant expansion rate:
① When we use Hubble's law with a constant H_0, we assume that the Universe has always expanded at the same rate.
② this would give a predicted distance D_{H_0} based purely on the redshift $z = 0.79$ and a simple linear relation between velocity and distance.

→ Actual cosmic Expansion is not constant:
① Universe's expansion rate has changed over time.
② Earlier in the univere's history, expansion was slower due to the influence of matter, which gravitationally slowed the expansion.
③ Most recently, dark energy has caused an acceleration in expansion.

→ If the universe had always expanded at the current rate (H_0), the supernova would be ~~closer~~ closer that it actually is. Because the expansion was slower in the past, the light from the supernova took longer to reach us. Actual distance we measure using the supernova's brightness (D_{SN}) is greater than predicted (D_{H_0}).

5. Let's see if we can use Hubble's Law to determine distances to galaxies in the MaNGA survey, at redshifts $z = 0.05 - 0.15$. For the benchmark cosmology model including dark energy, the distances to galaxies at z=0.15 and z = 0.05 are 713 Mpc and 222 Mpc respectively (estimated using Ned Wright's Cosmology Calculator: http://www.astro.ucla.edu/~wright/CosmoCalc.html)

At each end of this redshift range, how large would our distance error be if we used Hubble's Law to estimate the distance? Assume $H_0 = 70$ km s^{-1} Mpc^{-1}.

Hubble's law: $D_H = \frac{cz}{H_0}$ (to estimate distance)

for $z = 0.05$:

$D_H = \frac{3 \times 10^5 \times 0.05}{70} = \frac{15000}{70} = 214.3$ Mpc

for $z = 0.15$:

$D_H = \frac{3 \times 10^5 \times 0.15}{70} = \frac{45{,}000}{70} = 642.9$ Mpc

D_{SN} for $z = 0.05 = 222$ Mpc

D_{SN} for $z = 0.15 = 713$ Mpc

$z = 0.05$: error $= 7.7$ Mpc, % error $= \frac{7.7}{222} \times 100 = 3.5\%$

$z = 0.15$: error $= 70.1$ Mpc, % error $= \frac{70.1}{713} \times 100 = 9.8\%$