ASTR 1120
:: Stars and Galaxies ::

Hubble's Law and Expansion of the Universe

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July 2010

Learning Goals

- What is Hubble's Law? What does it tell us about the Universe?
- Is the Universe expanding? What does it mean to live in an expanding Universe?

“Spiral Nebula” Confusion

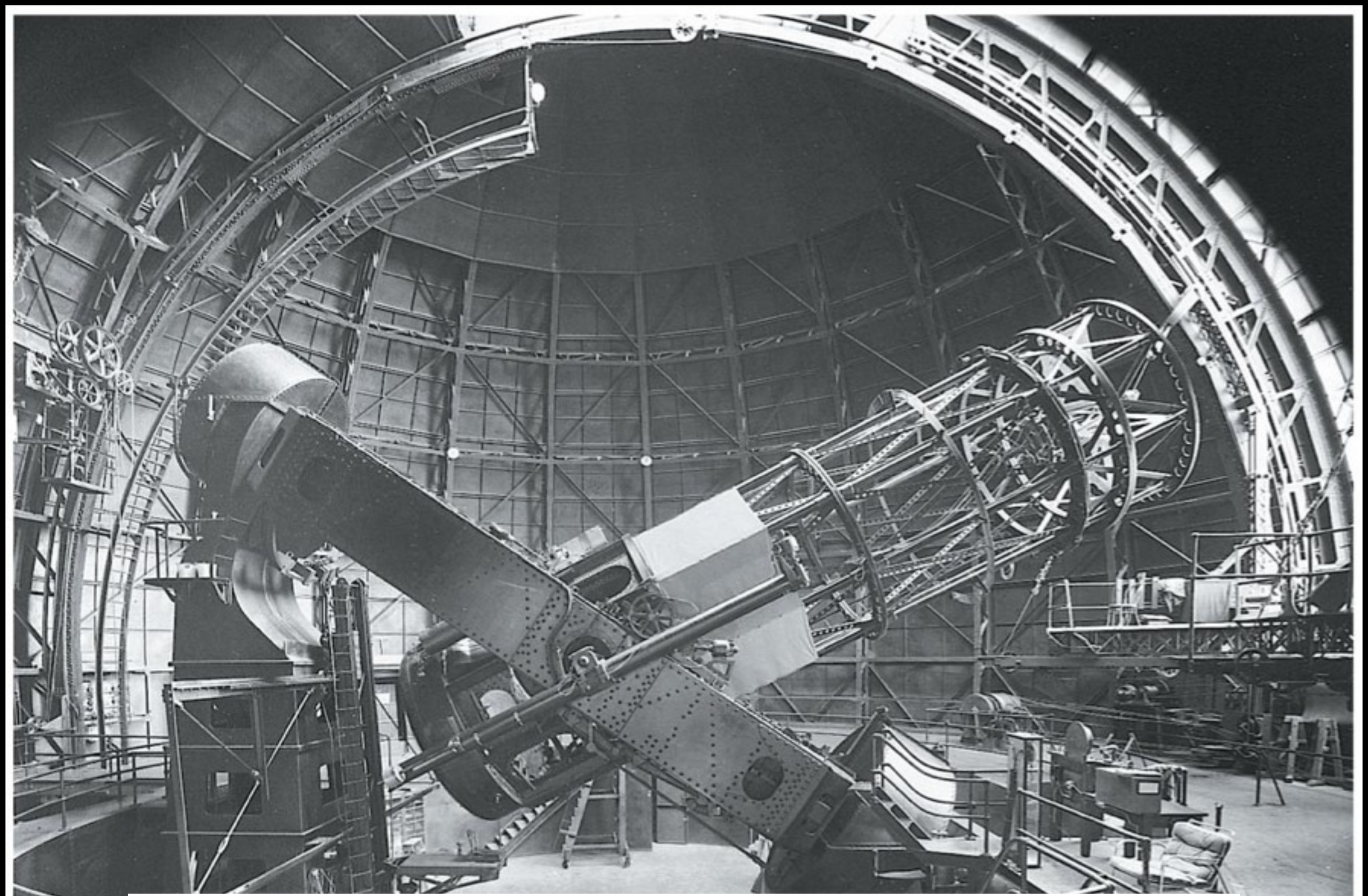
- Before 1924, “spiral nebulae” were thought to be small objects located inside the Milky Way

“The Great Andromeda Nebula”

Edwin Hubble clears the air

- Using Cepheid variables in Andromeda, he estimated the distance to the "spiral nebula"
  - These stars were far outside the reaches of the Milky Way!
- This discovery (his first big one) changed the view of the universe
- Rather than the Milky Way being the single galactic member of the universe, it became just one of many!

Hubble's cutting-edge technology



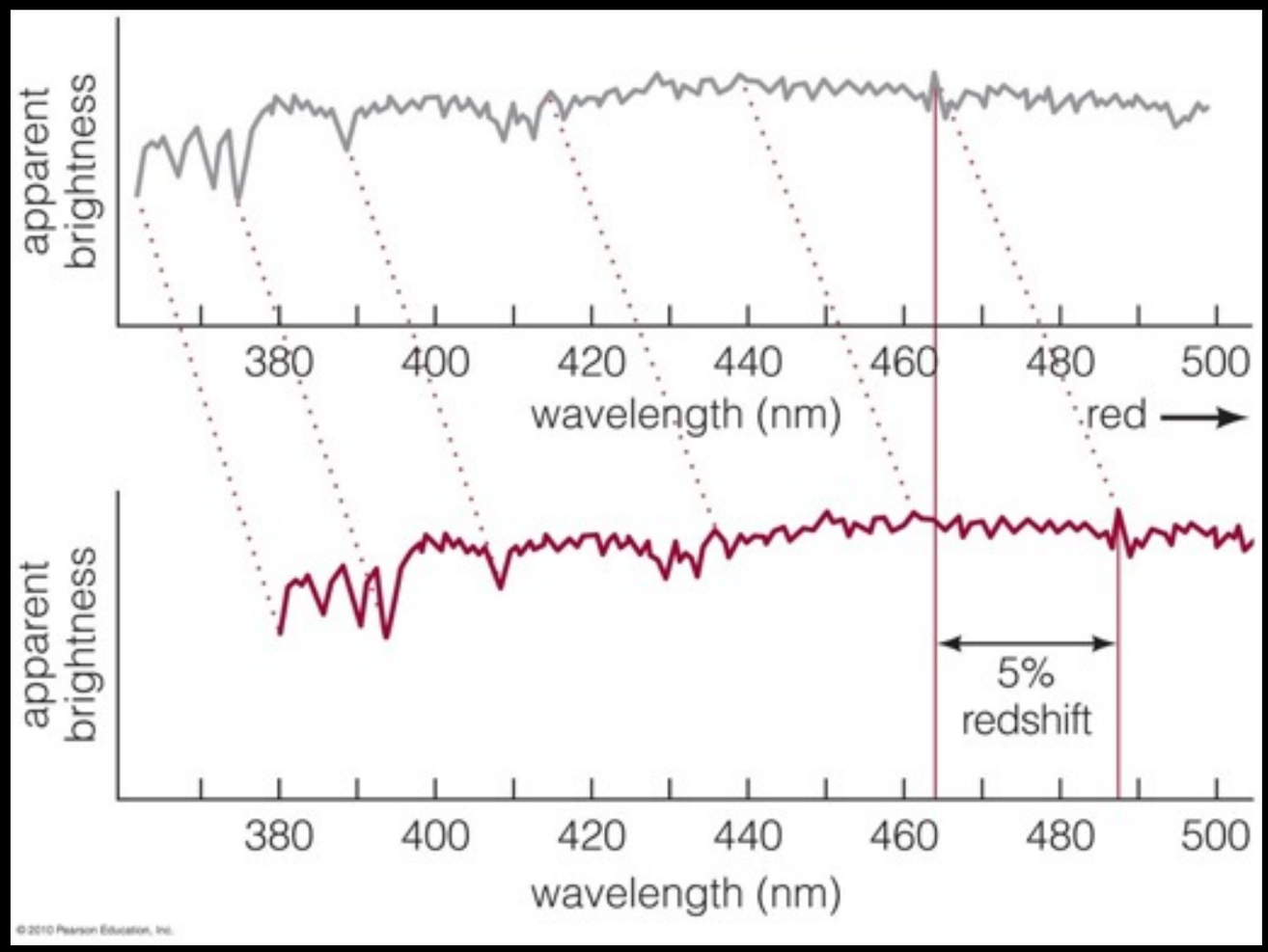
Mount Wilson Observatory: 100-inch telescope
World's largest telescope for 30 years

That wasn't enough for Hubble

- Hubble turned his attention to other galaxies
- He found that all galaxies seem to be moving away from us
  - Not terribly surprising, this had been know for ~15 years
- However, he was the first to measure both speed *and* distance

How did Hubble work out these distances?

- Distances: He made an incorrect, but lucky standard candle assumption
  - Assumed the brightest object in all galaxies was always the same luminosity
- Redshifts: Looked at the spectra from these galaxies and match with expected spectra



Tutorial Time?

- Hubble’s Law (not in book)

Hubble showed that:

A) The further away we look in the universe, the faster things are moving

B) The further away we look in the universe, the slower things are moving

C) Everything in the universe is moving away at the same speed

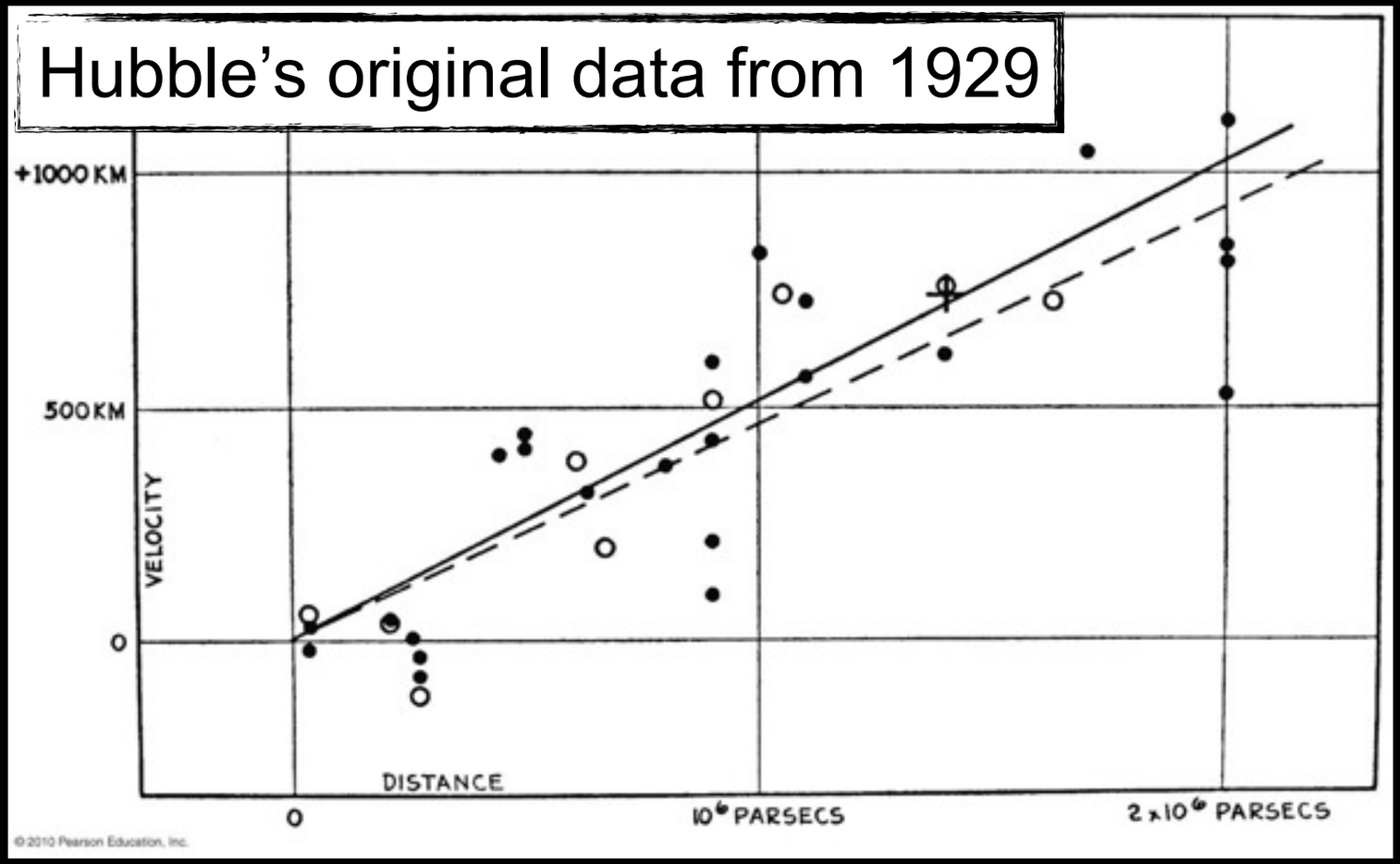
D) Everything in the universe is staying still, we're just the ones moving

Hubble showed that the universe is expanding!

Hubble's Law:

$$v = H_0 \times d$$

- v: Velocity of recession (doppler shift) (km/sec)
- H_0: Hubble's Constant (km/sec/Mpc)
- d: Distance (Mpc)



What causes the scatter?

Possible source of error?

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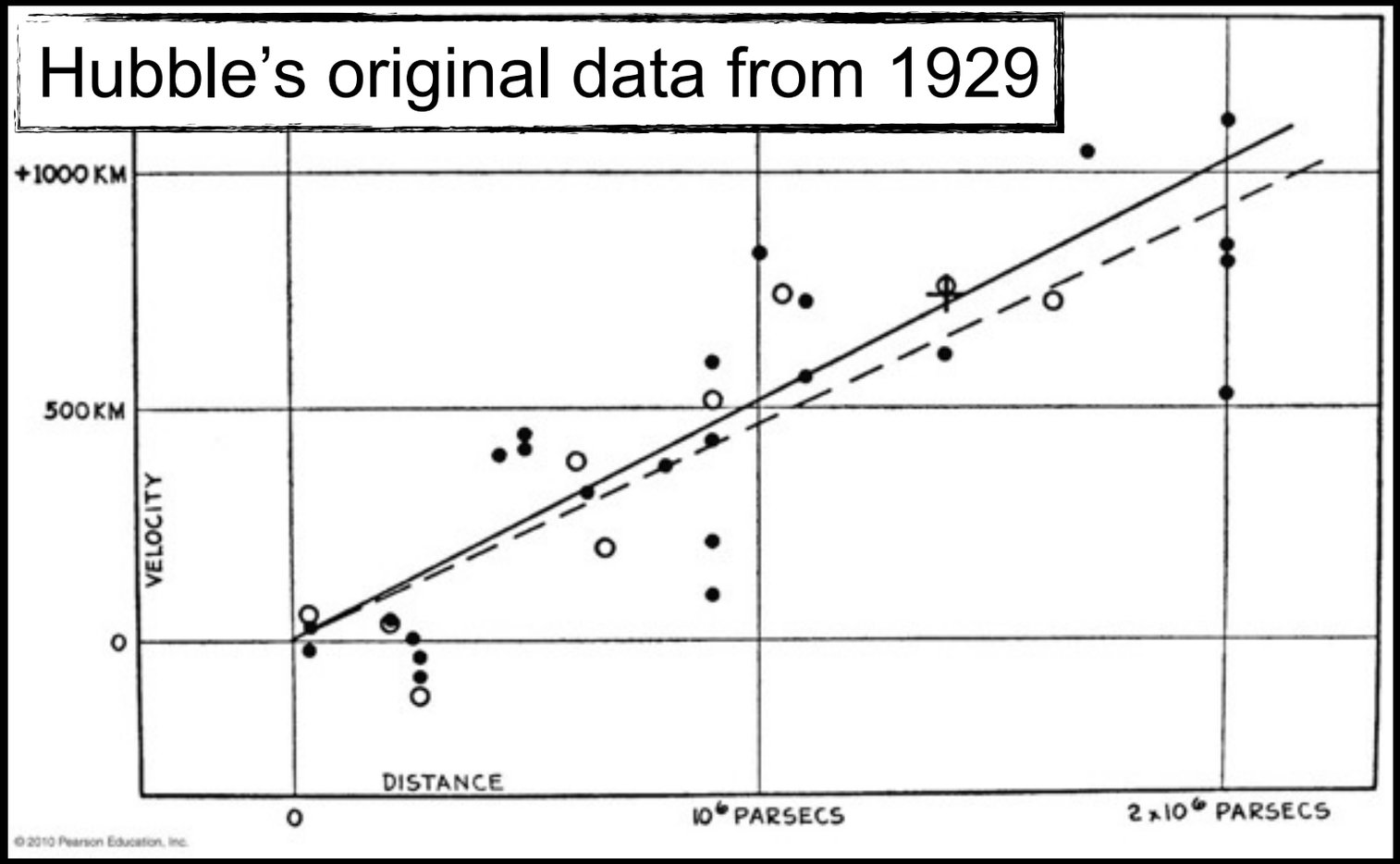


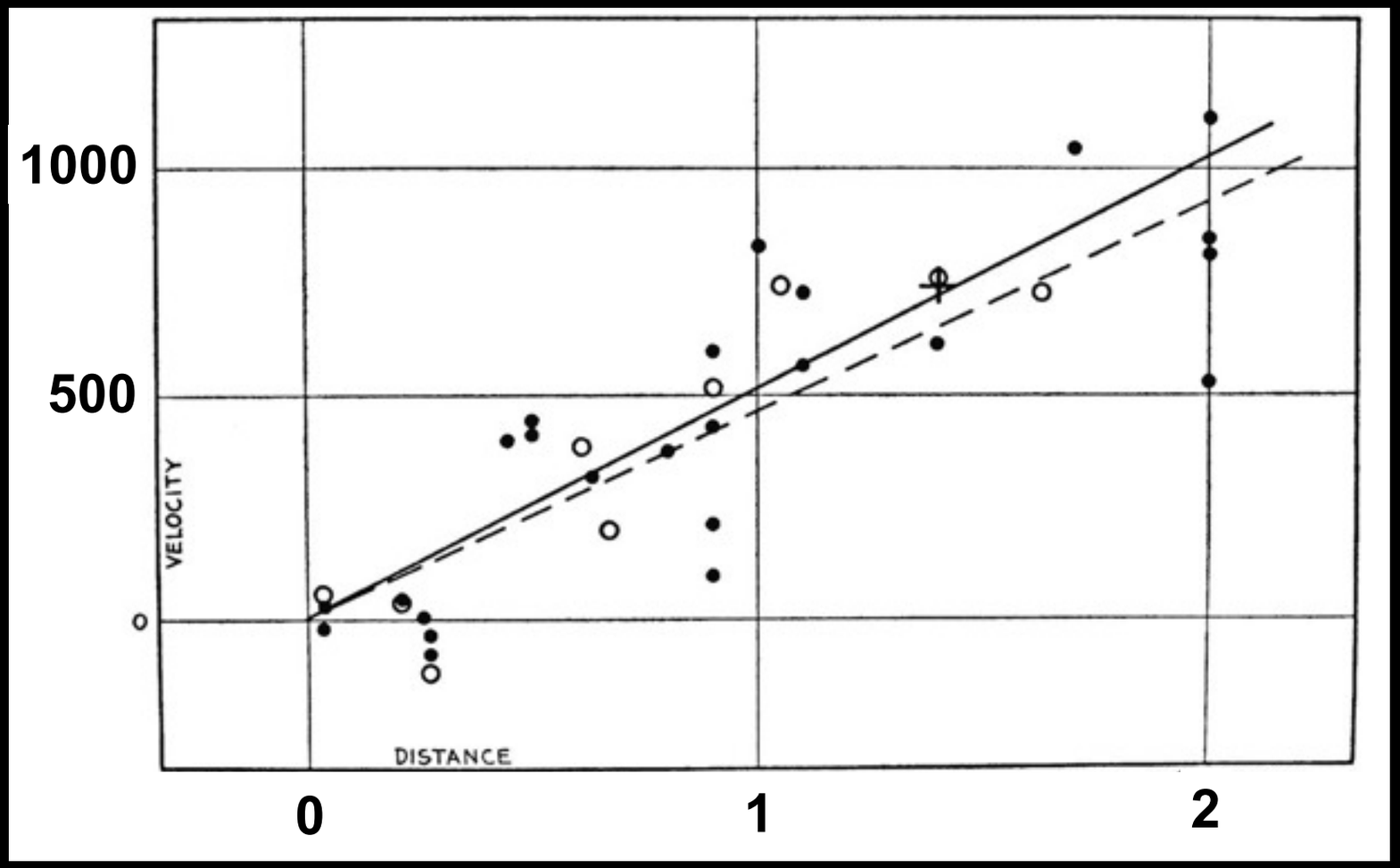
What causes the scatter?

- Random velocities of nearby galaxies

Possible source of error?

- Unreliable distance estimates

From Hubble's original plot, what is the value of the Hubble constant?



A) 50 km/sec/Mpc

B) 100 km/sec/Mpc

C) 500 km/sec/Mpc

How fast is the universe expanding?

- Measuring H_0 is difficult: $v = H_0 \times d$

  $H_0 = v / d$

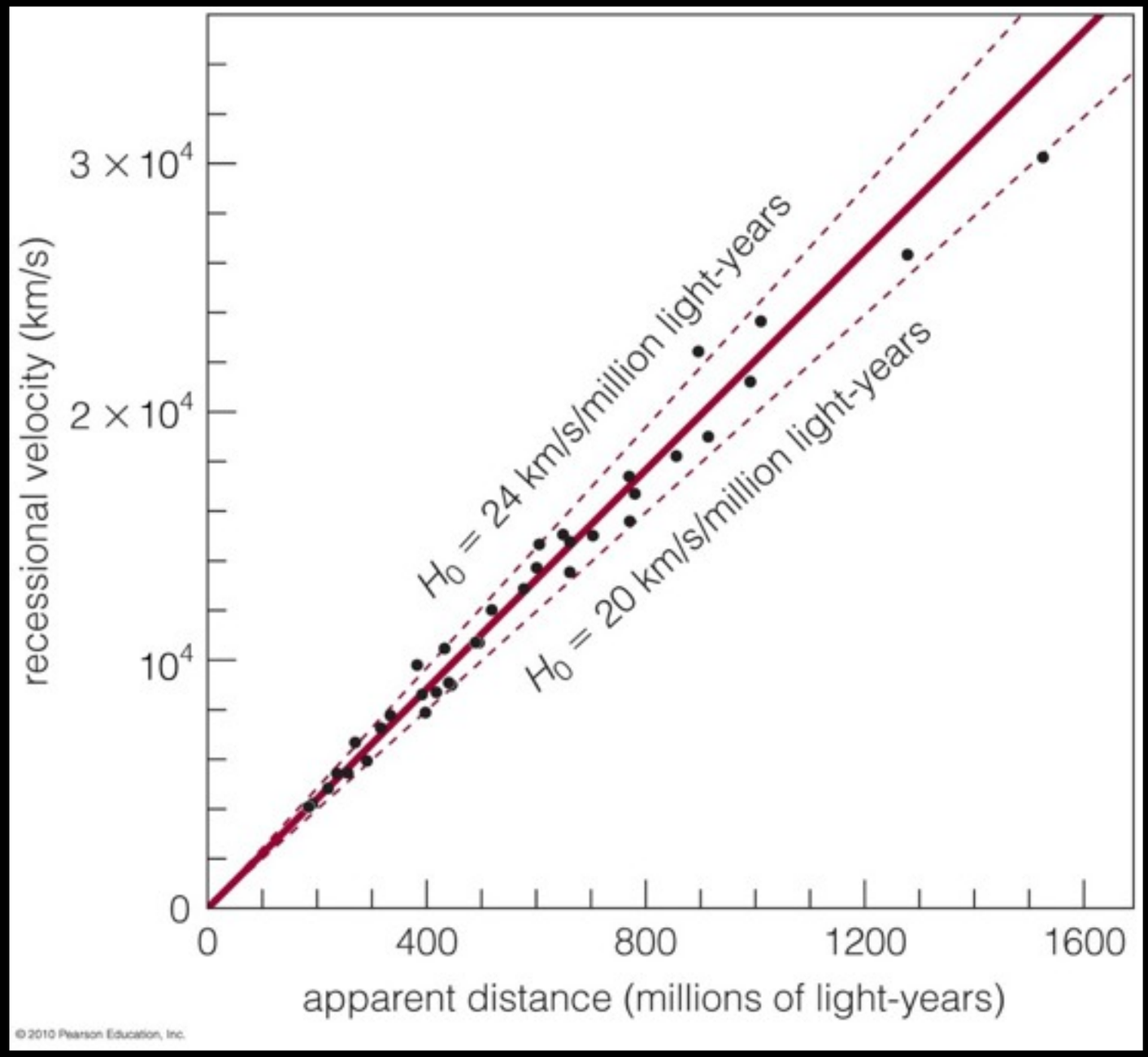
- Nearby galaxies: “random” motions through space similar to expansion velocity. Doppler shifts we measure are not purely from the expanding universe
- Far away galaxies: large expansion velocities, but hard to measure distances

Hubble Space Telescope was sent on a mission to find the Hubble Constant

- Observed Cepheid variables in galaxies out to 60 million light-years

Better than Cepheids: White Dwarf Supernovae

- First, use Hubble Cepheids to nail down luminosity of white dwarf supernovae
- Then use the supernovae themselves to peer even further
- Leads higher accuracy in the Hubble Constant



If we can nail down H_0...

- We can use Hubble's law itself to estimate vast distances!
- Measure velocity (from doppler shift), then use:

$$d = v / H_0$$

- Example: if H_0 = 72 km/s/Mpc and we see a galaxy receding at 1000 km/s, then:

d = (1000 km/s) / (72 km/s/Mpc) = 13.9 Mpc
= 45.3 million ly

Your friend leaves your house. She later calls you on her cell phone, saying that she's been driving at 60 mph directly away from you the whole time and is now 60 miles away. How long has she been gone?

A) 45 minutes

B) 60 minutes

C) 90 minutes

D) 120 minutes

E) Not enough information to tell

Another friend left your house at the same time and later calls you, says he's been driving 90 mph away from you and is now 90 miles away. How long has he been gone?

A) 45 minutes

B) 60 minutes

C) 90 minutes

D) 120 minutes

E) Not enough information to tell

Another reason to measure H_0…

- The Hubble constant also provides the age of the universe!
- How?
  - Imagine the expanding universe going backwards in time…
  - Large expanding universe (seen today) suggests that in the past everything was much closer together…
  - A single infinitely dense origin of all space, matter, energy: The Big Bang

The Age of the Universe

- IF the universe has always had a constant expansion velocity:

distance = velocity x time ➡ time = distance / velocity

Hubble's Law: velocity = H_0 x distance ➡ H_0 = velocity / distance

Time (age of the universe) = 1 / H_0

- For 72 km/sec/Mpc : Age ~ 13.7 billion years
  - For larger H_0, shorter time
  - For smaller H_0, longer time

Are we in the ballpark?

Time (age of the universe) = 1 / H_0 ~ 13.7 billion years

✓ Age of the solar system ~ 4.6 billion years old

✓ Age of the oldest star clusters ~ 12-13 billion years old

Awesome! That seems pretty consistent, we'll talk about whether or not this is exactly right later in the course

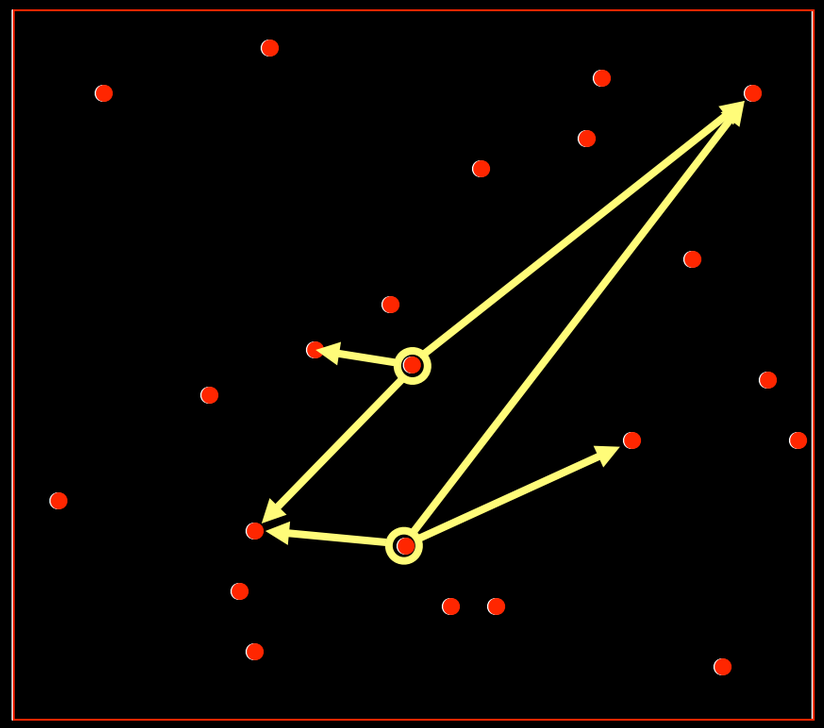
How should you think about the expanding universe?

- DON'T think about it as an explosion of galaxies flying through space

- DO think about it as fabric of space between galaxies stretching out and carrying galaxies away from each other

- Thought question: Why don't the galaxies themselves expand?

Expansion as a STRETCH



- There is no center!
- Every galaxy sees every other galaxy receding away

Expansion Demo

How do we talk about “distance” in an expanding universe?

- Image that a supernova goes off in a distant galaxy 400 million years ago
- Light from the supernova begins traveling toward the Milky Way at the time of the explosion
- Today, we see the light from the supernova explosion, but what happened to the galaxies in the mean time?

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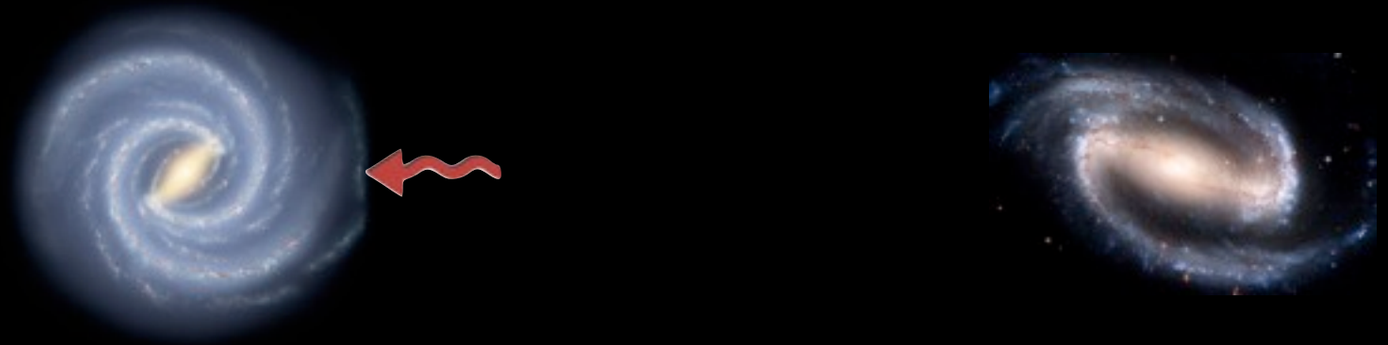
400 million years ago

Today



The universe expanded and the galaxies are further apart!

Distances become fuzzy ➡ lookback time is more accurate

How does light deal with an expanding universe?

- As light travels through the expanding universe, it “feels” the effects of this stretching

If the wavelength of light is stretched as it travels, is the light itself getting redder or bluer?

A) Redder

B) Bluer

C) It depends on what direction the galaxy was moving when it was emitted.

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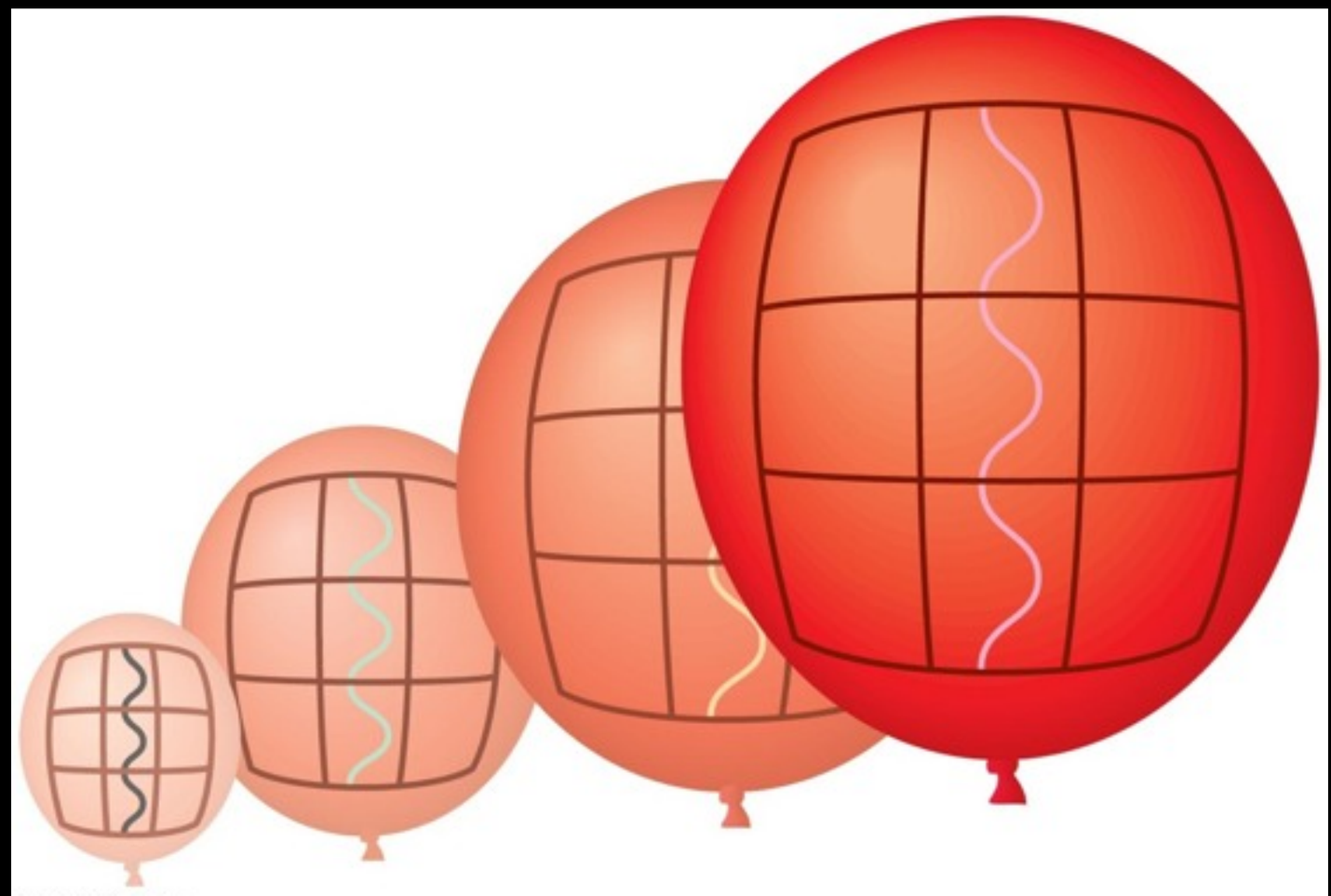
Cosmological Redshift



Summary

- Hubble figured out that not only is the Universe limited to the Milky Way, but that all of the distant galaxies are expanding away from us
  - Hubble's Law: $v = H_0 \times d$
- We can use the Hubble Constant to get the distances to galaxies far, far away
- Can get an estimate of the age of the Universe from Hubble's Constant
- Receding galaxies pointed to an expanding universe -- everything is moving away from everything else