"Okay, it’s morning and you’re getting ready to go to work. You pull on your pants. Do you fasten and then zip or zip and then fasten?”

Garibaldi, Babylon 5

Reading updated- final list.

HW4 on-line now and due next Monday!

Group Project 2 and groups on-line now and due Friday April 26. Will have ~20 minutes this and next Wednesdays.

Push handing T2 back to Friday?

Points: 2 quizzes left: 150 pts total

1 HW left: 125 pts total

3 tests (1 left): 300 pts total.

2 group Projects: 100 pts total.

Labs: somewhat variable.

Take Test 3 OR the final, but NOT BOTH.

There *will be* a helpful document on Blackboard soon-ish.

NOTE: blackboard's "%" and "Total points" at the top will be incorrect but your individual grades and point total column I'm adding at the bottom should be correct.

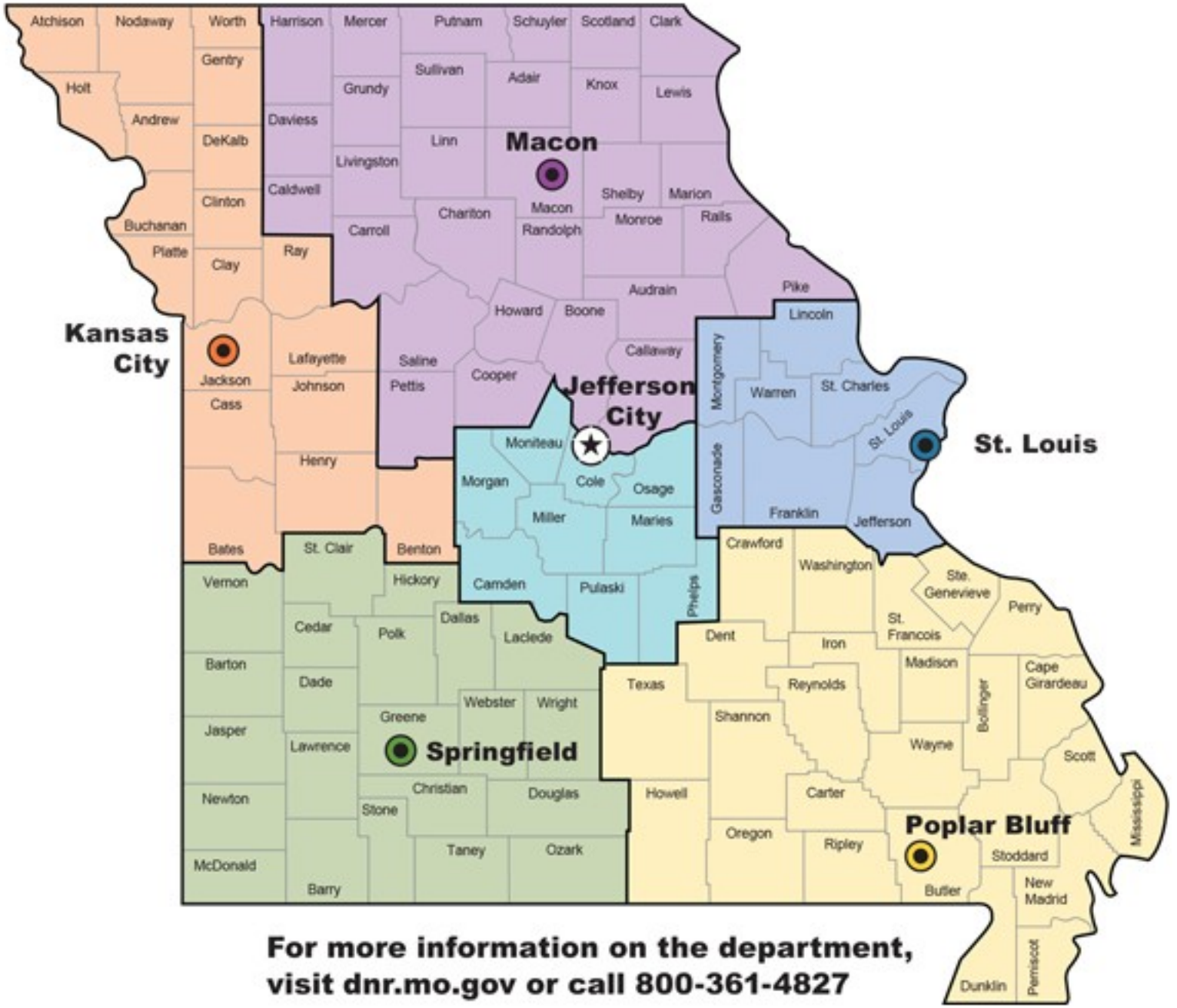
You must include your full name, first and last on all work.

On scantrons, you need to do last name before first name.

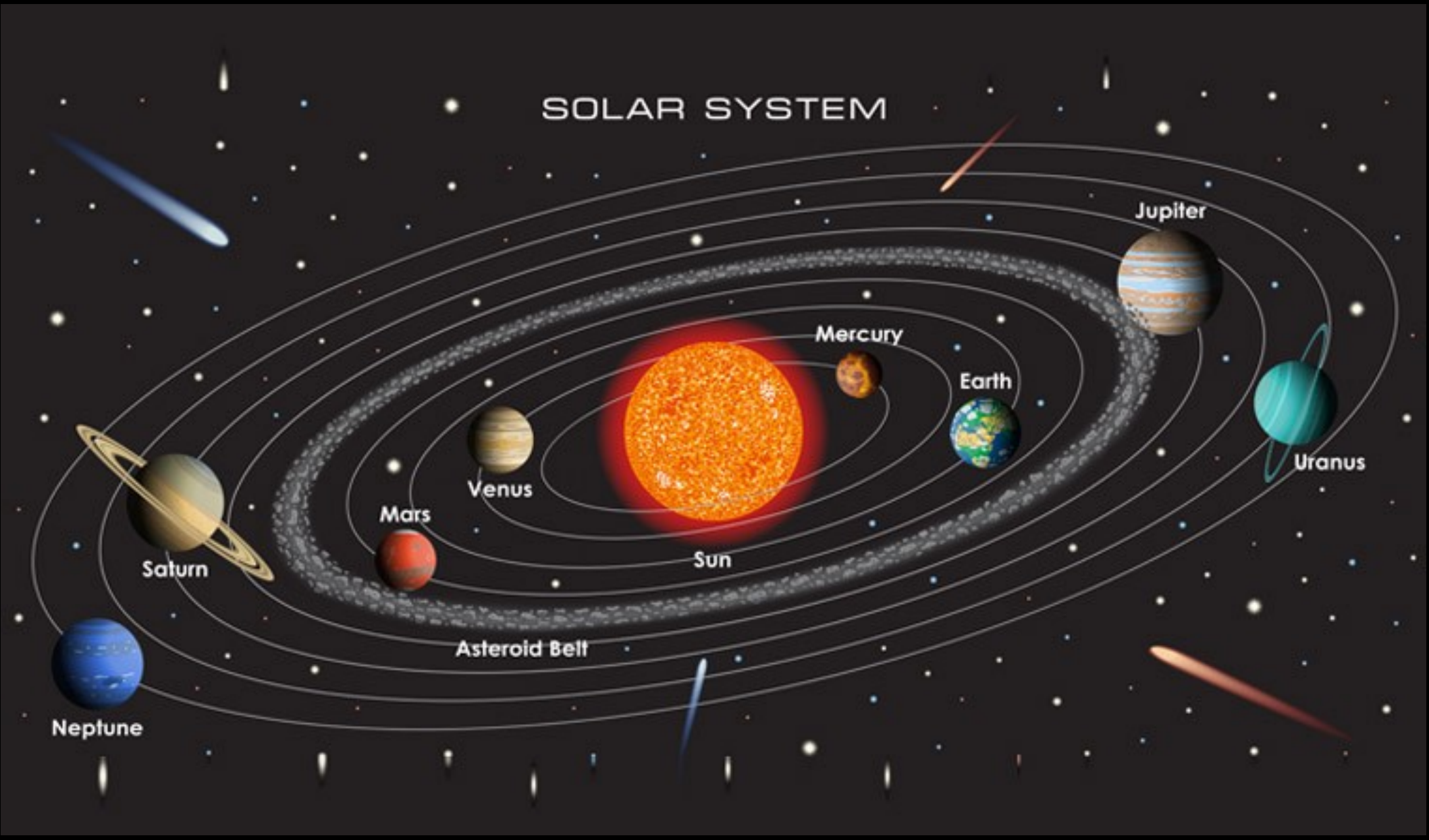
You will not receive any credit if these criteria are not followed.

Cosmology.

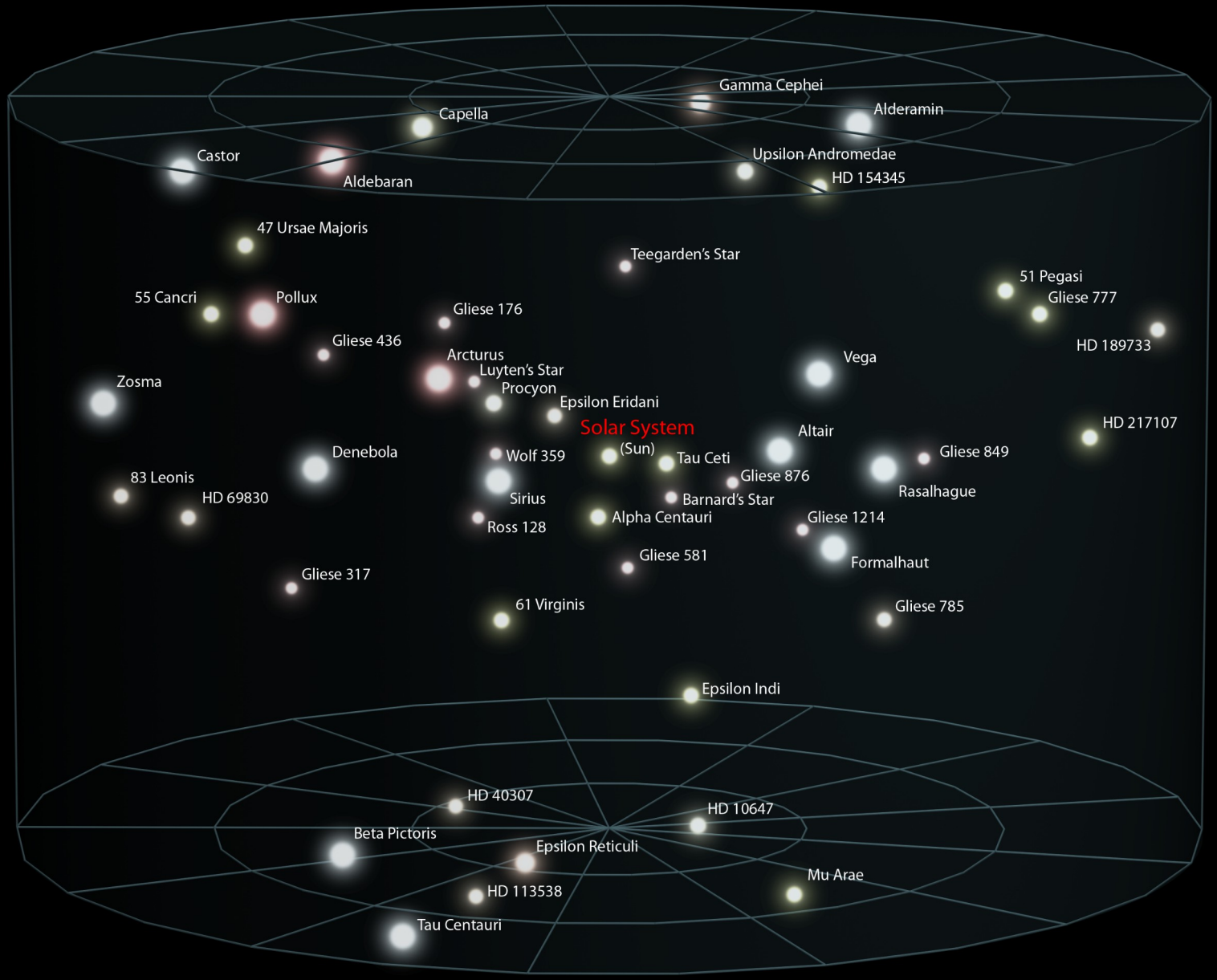
Cosmology is the study of the Universe as a whole. It is about objects larger than individual galaxies and the evolution of the Universe and its contents.



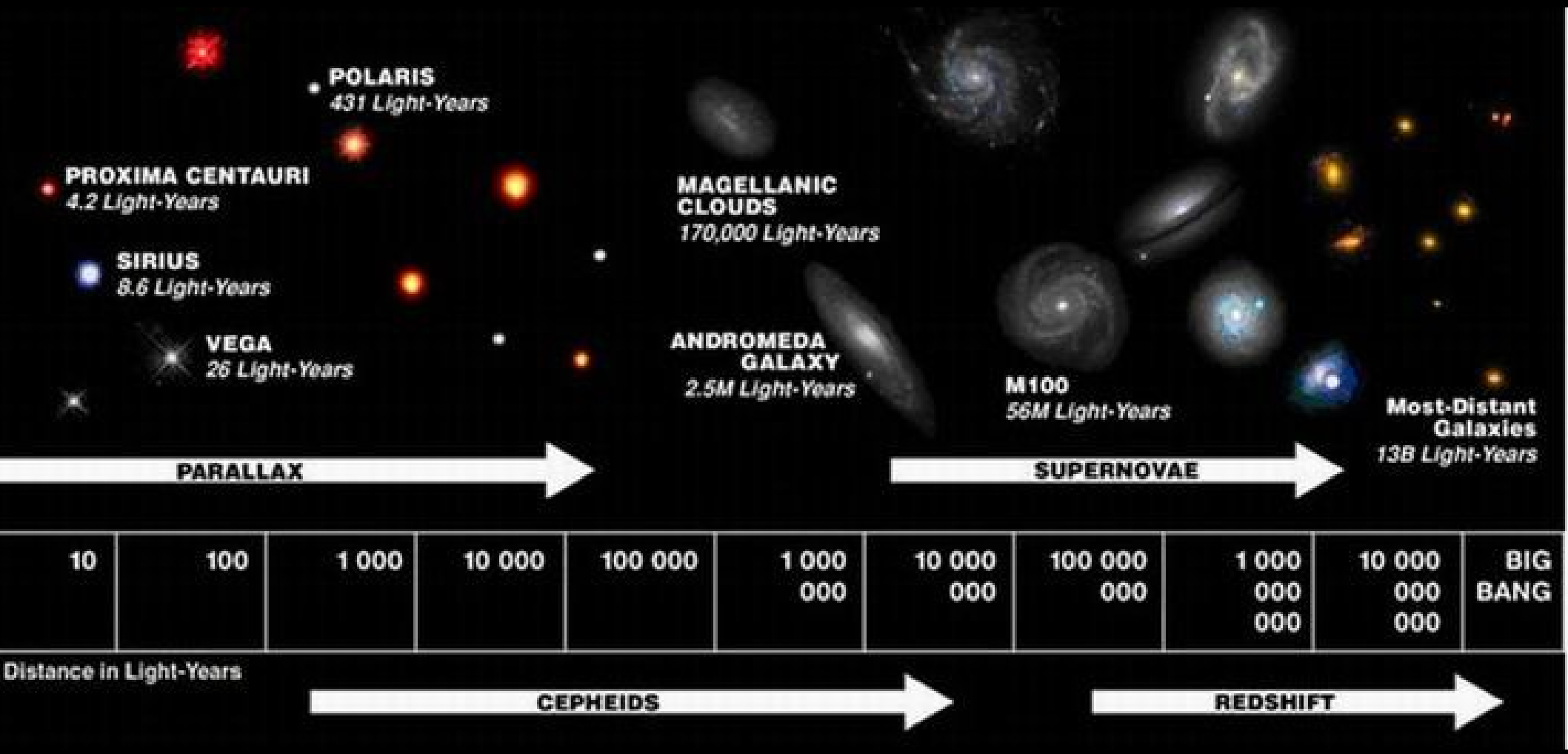
For more information on the department, visit dnr.mo.gov or call 800-361-4827


SOLAR SYSTEM
Jupiter
Mercury
Earth
Uranus
Venus
Mars
Saturn
Sun
Asteroid Belt
Neptune

INTERSTELLAR NEIGHBORHOOD

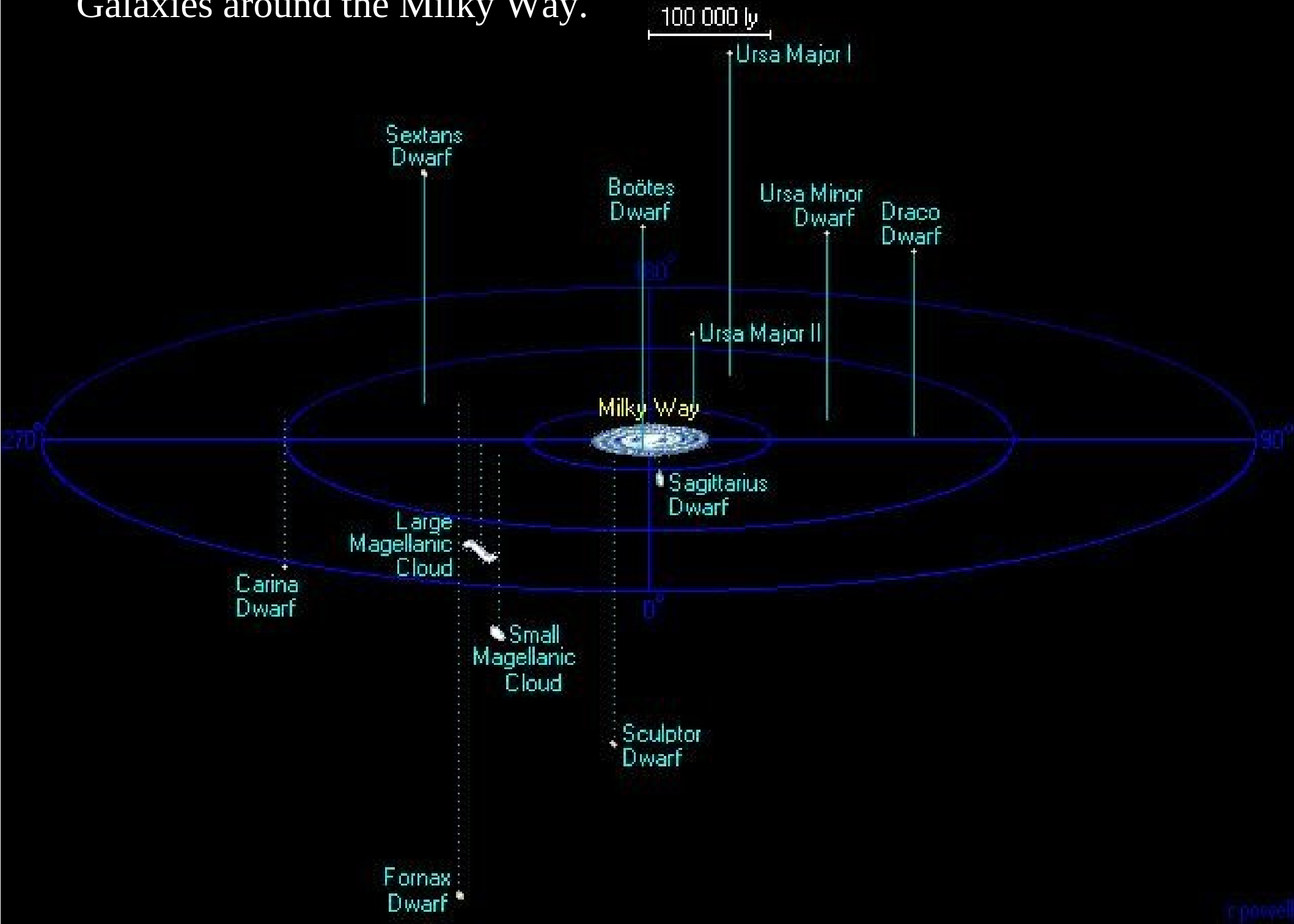


distance ladder




YOU ARE HERE

Galaxies around the Milky Way.



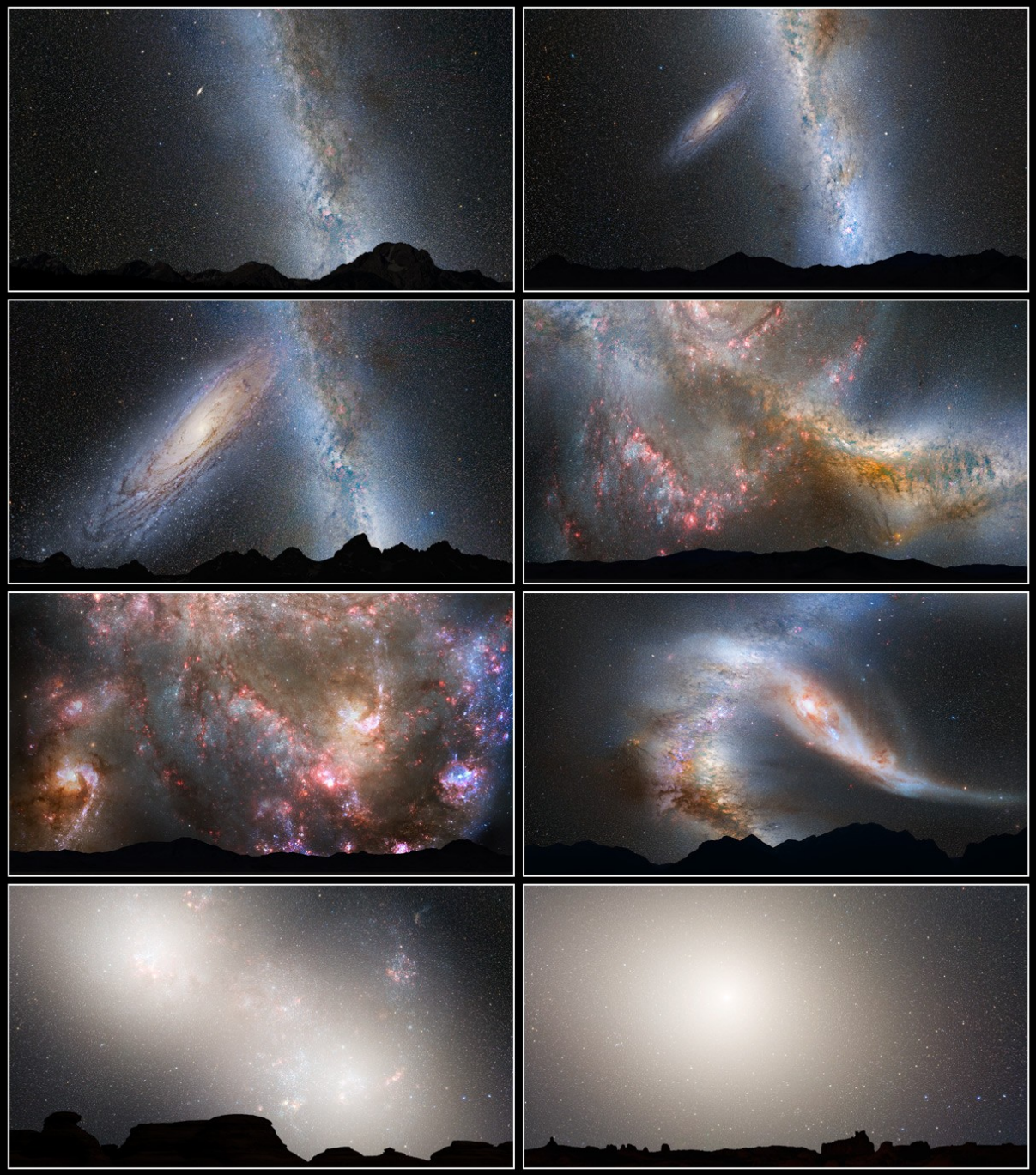


Illustration Sequence of the Milky Way and Andromeda Galaxy Colliding

NASA, ESA, Z. Levay and R. van der Marel (STScI), T. Hallas, and A. Mellinger ▪ STScI-PRC12-20b

The Milky Way and Andromeda galaxies.

The 2 most massive galaxies in our group are pulling on each other.

And in another 3-4 billion years they will collide.

Take-aways

Most galaxies are in groups or clusters.

Most galaxies in clusters are ellipticals.

Most spiral galaxies exist in ‘the field’ (not a cluster) or in small groups.

Galaxies in clusters are likely to be disrupted into elliptical galaxies.

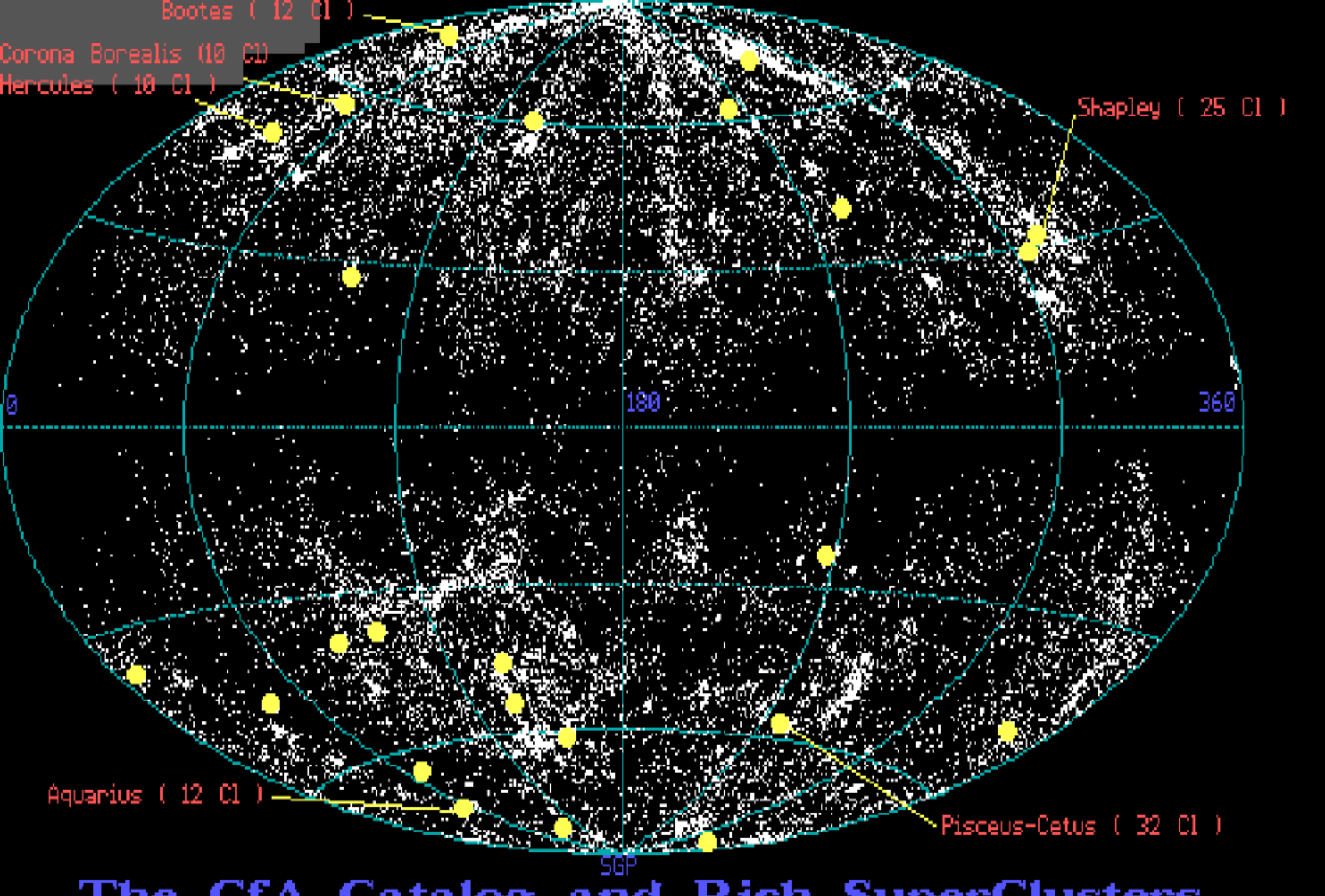
Quiz 14: Classify this galaxy.

A) Elliptical
B) Spiral
C) Barred spiral
D) Irregular
E) None of those.

Superclusters

As astronomers look on larger and larger scales, we see groupings of groupings of galaxies, with voids (empty regions) between them. This helps to provide clues as to how the Universe formed.

The next slide shows a map of galaxies projected on to the sky. The middle has fewer because that's where our galaxy blocks them. The yellow dots are galaxy clusters.

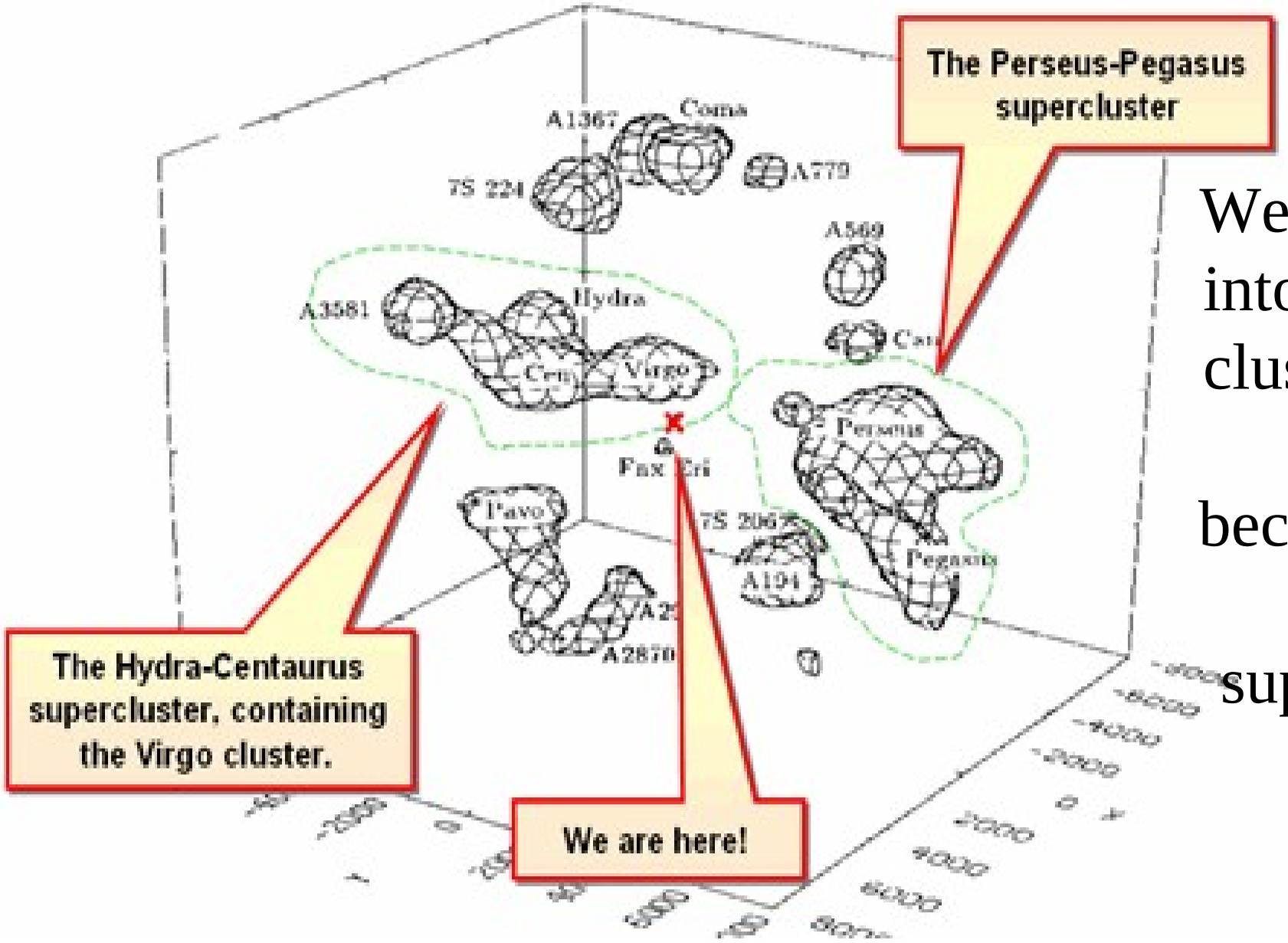


The CfA Catalog and Rich SuperClusters

Superclusters are from Einasto et al. 1994 List (Richness>5)

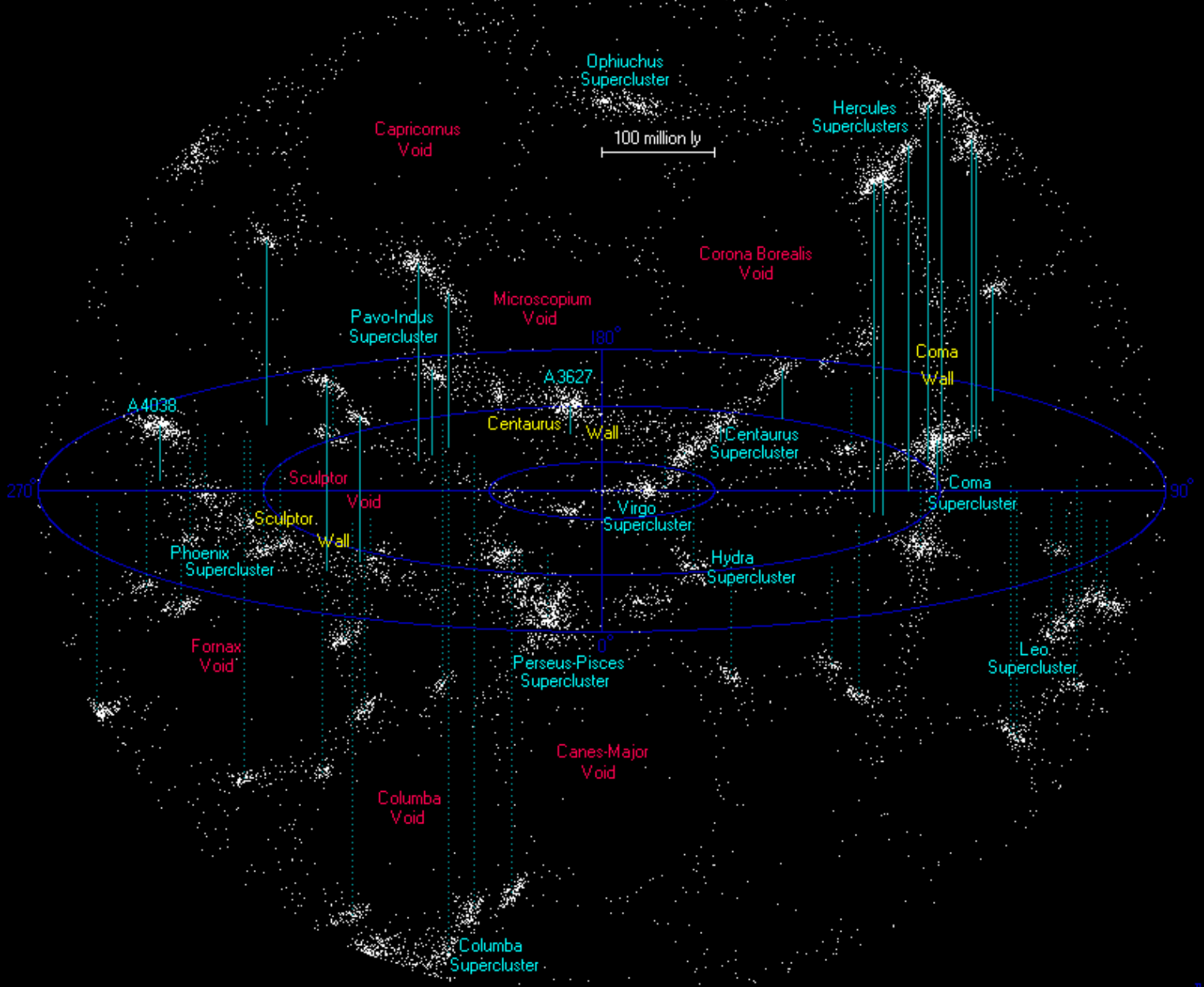
Graphics by A. Kravtsov (Astro Space Center)

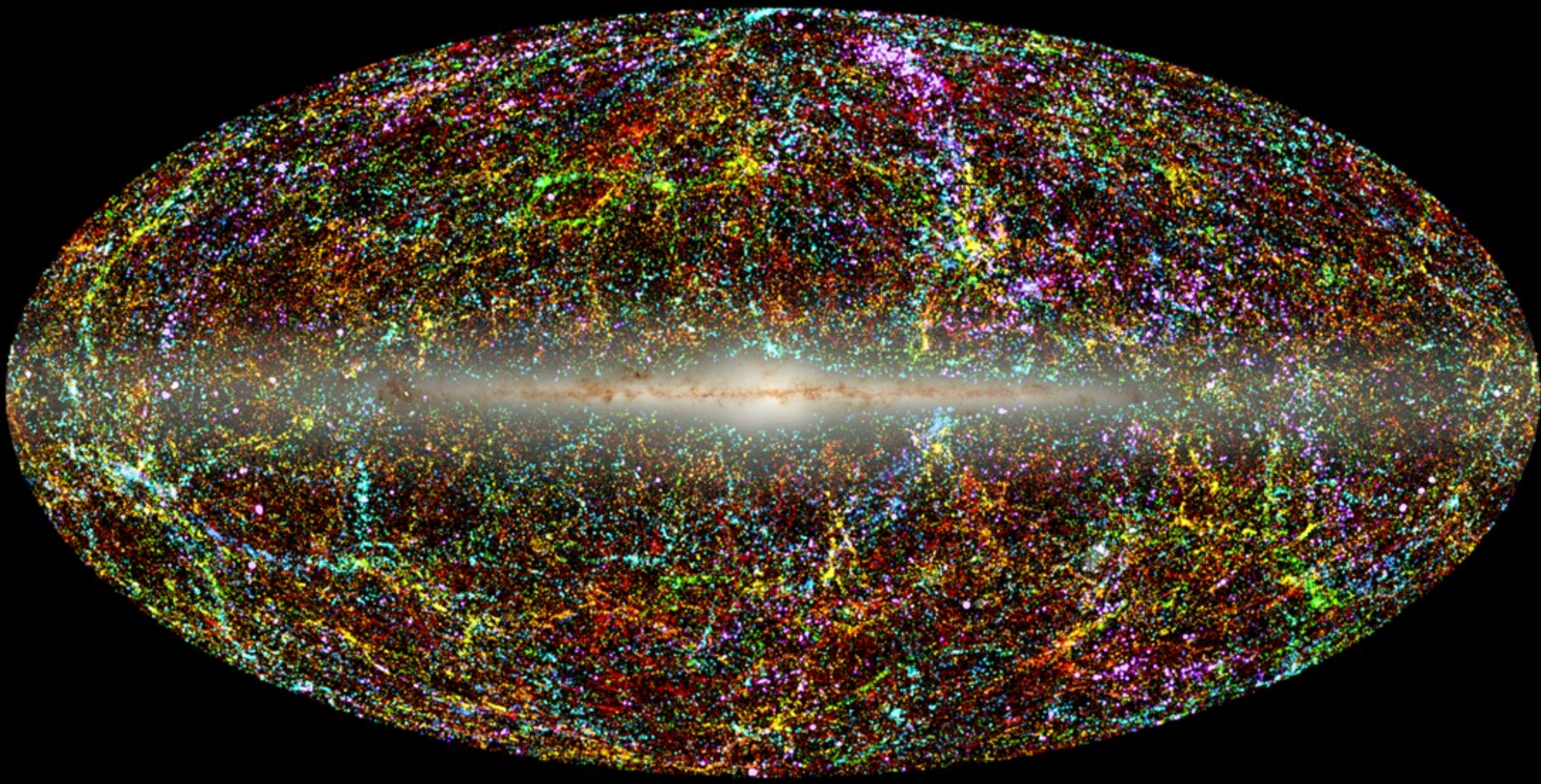
Our region of space including the local clusters.



We are falling into the Virgo cluster, which itself is becoming part of a supercluster.

Another map of galaxies. Notice how there are groups and then regions between them, where there are only a few galaxies (called voids).





Another map (including where our galaxy blocks light) of galaxy locations. Again, note the concentrations and the regions between.

Large-scale structure

Superclusters appear to be connected by filaments and sheets, with voids (not completely empty) in between.

Superclusters do not form superduperclusters.

The Universe is homogeneous and isotropic

As we look at all these galaxies, both near and far, we see that they are made of the same stuff and at the same temperatures. None of them contain ‘superstars’ but just regular stars an gas.

On scales bigger than 200Mpc, the Universe is homogeneous. Each 200Mpc cube contains about the same amount of stuff.

It is also isotropic- that is, it has the same temperatures.

The Universe is homogeneous and isotropic

On large scales (>600 million light years) the Universe is the same in all directions; contains about the same amount of ‘stuff’ and at roughly the same temperature.

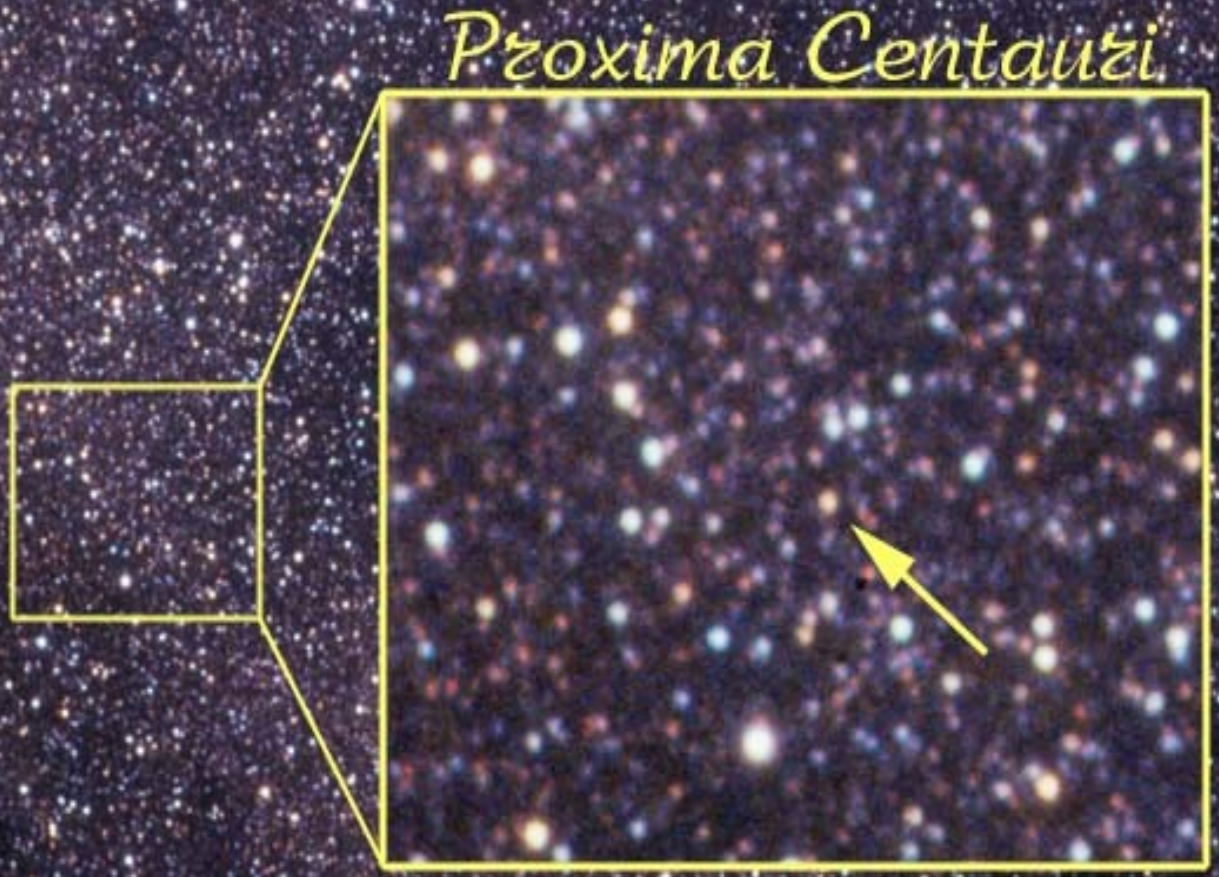
There is no preferred direction.

This is an extremely important property!

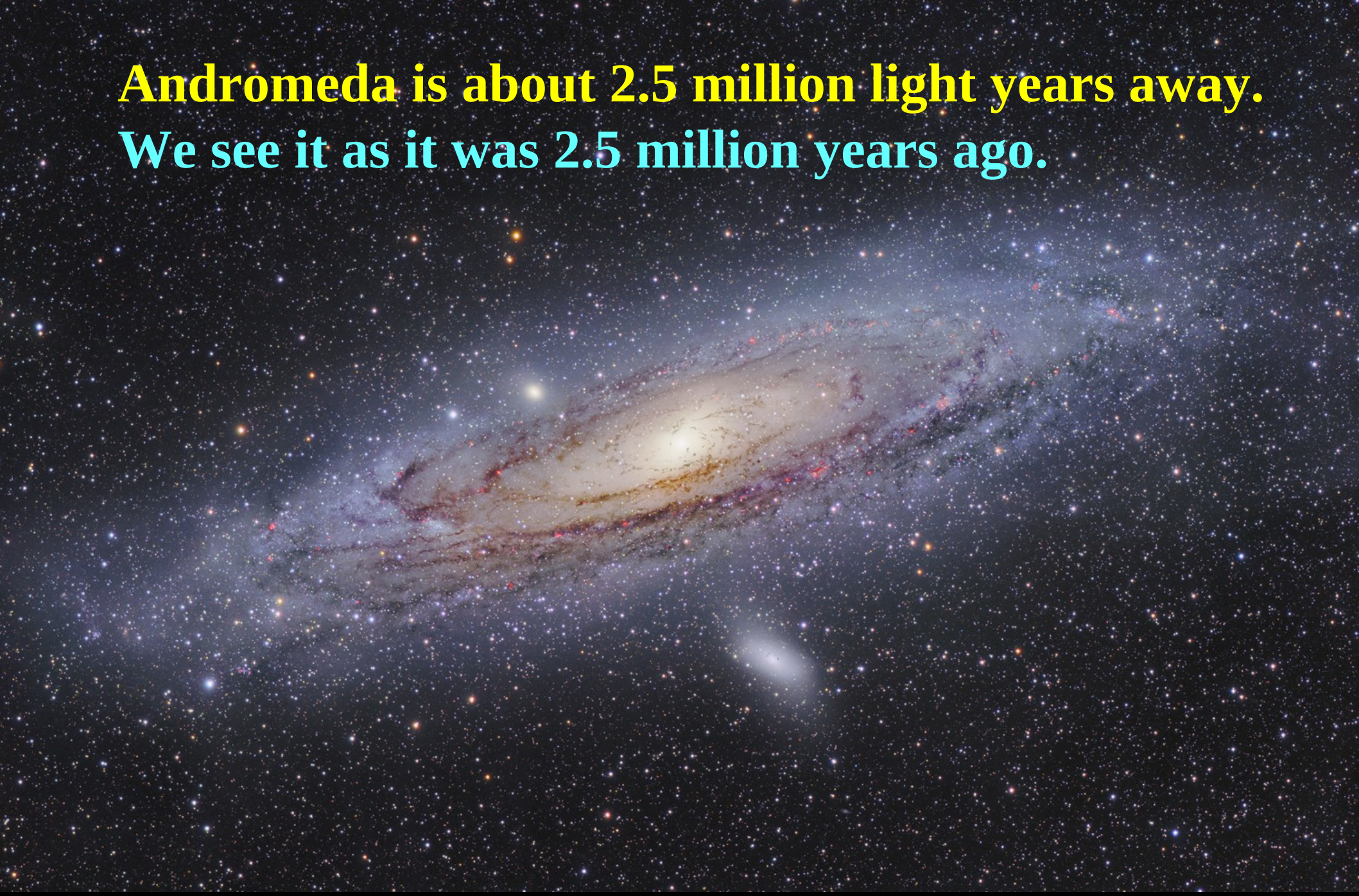
Distance as time.

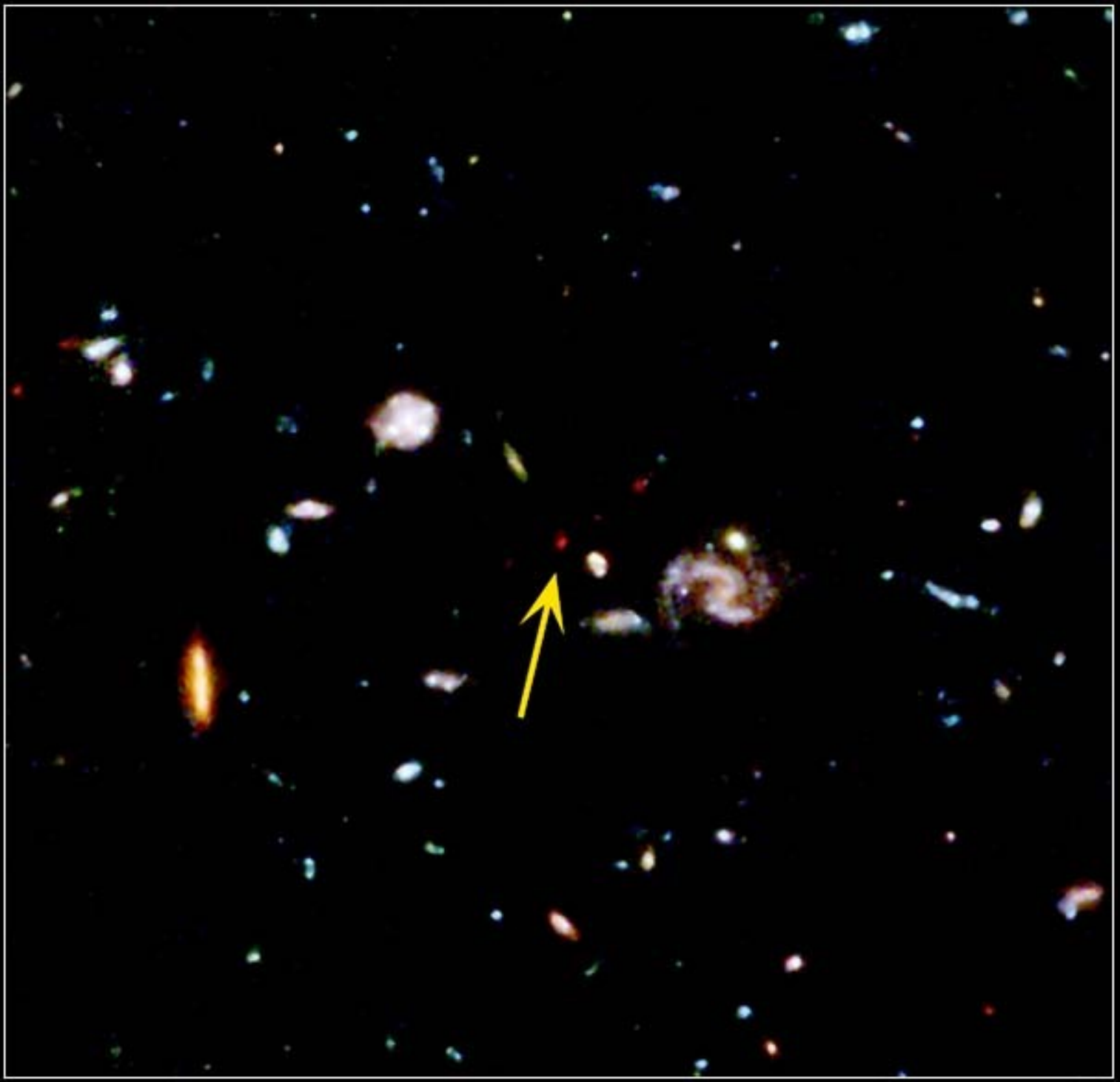
A lightyear is a measure of distance…..
But it takes light 1 year to go 1 lightyear.
The farther away we look, the farther back in time we see.

The nearest star is about 4 light years away. We see it as it was 4 years ago.



Marco Lorenzi, 2003


Andromeda is about 2.5 million light years away.
We see it as it was 2.5 million years ago.



Distant Galaxy in the Hubble Deep Field HST • WFPC2

PRC96-24b • ST ScI OPO • June 26, 1996 • K. Lanzetta (SUNY Stony Brook) and NASA

This galaxy is about 13.2 billion light years away. We see it as it was 13.2 billion years ago!

Summation:

We have tools to determine how far away things are.

The most distant galaxies must be measured using Type Ia supernova.

Most galaxies are in groups or clusters.

Our galaxy is part of a group: eventually we will collide with Andromeda, and our group is falling into the Virgo cluster, which itself is falling into a supercluster.

On large scales, the universe consists of superclusters and concentrations of galaxies, and voids, where there are few galaxies.

On scales larger than 200Mpc (~600Mly), the universe is homogeneous and isotropic (the same everywhere).

Galaxies in the Universe

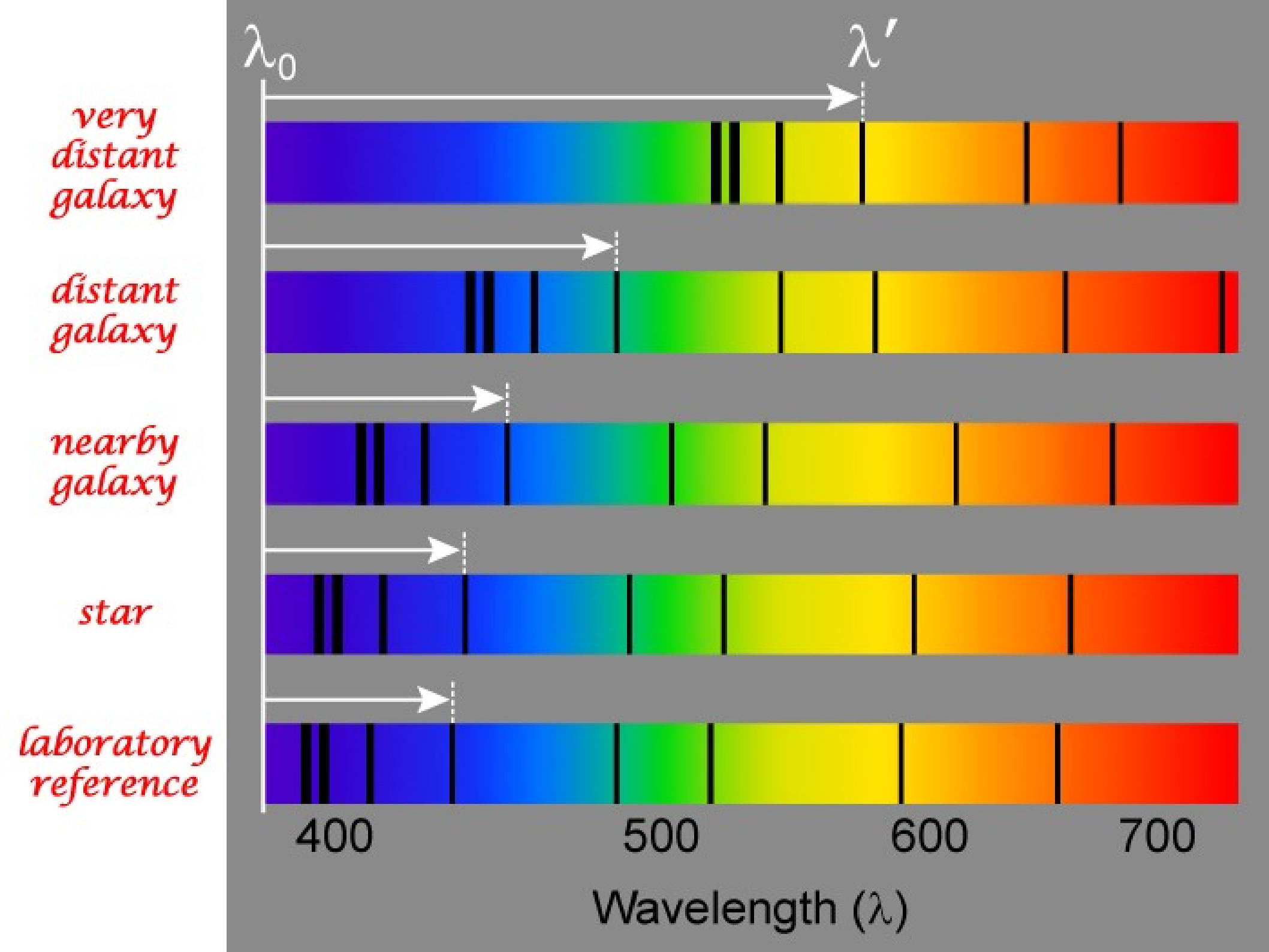
In the 1920s, Edwin Hubble looked at galaxies. He measured redshifts for about 10 galaxies. Using Cepheid variables, he determined the distances to the galaxies.

Then he organized them as distance versus redshift.

Side Note: Red(blue)shift:

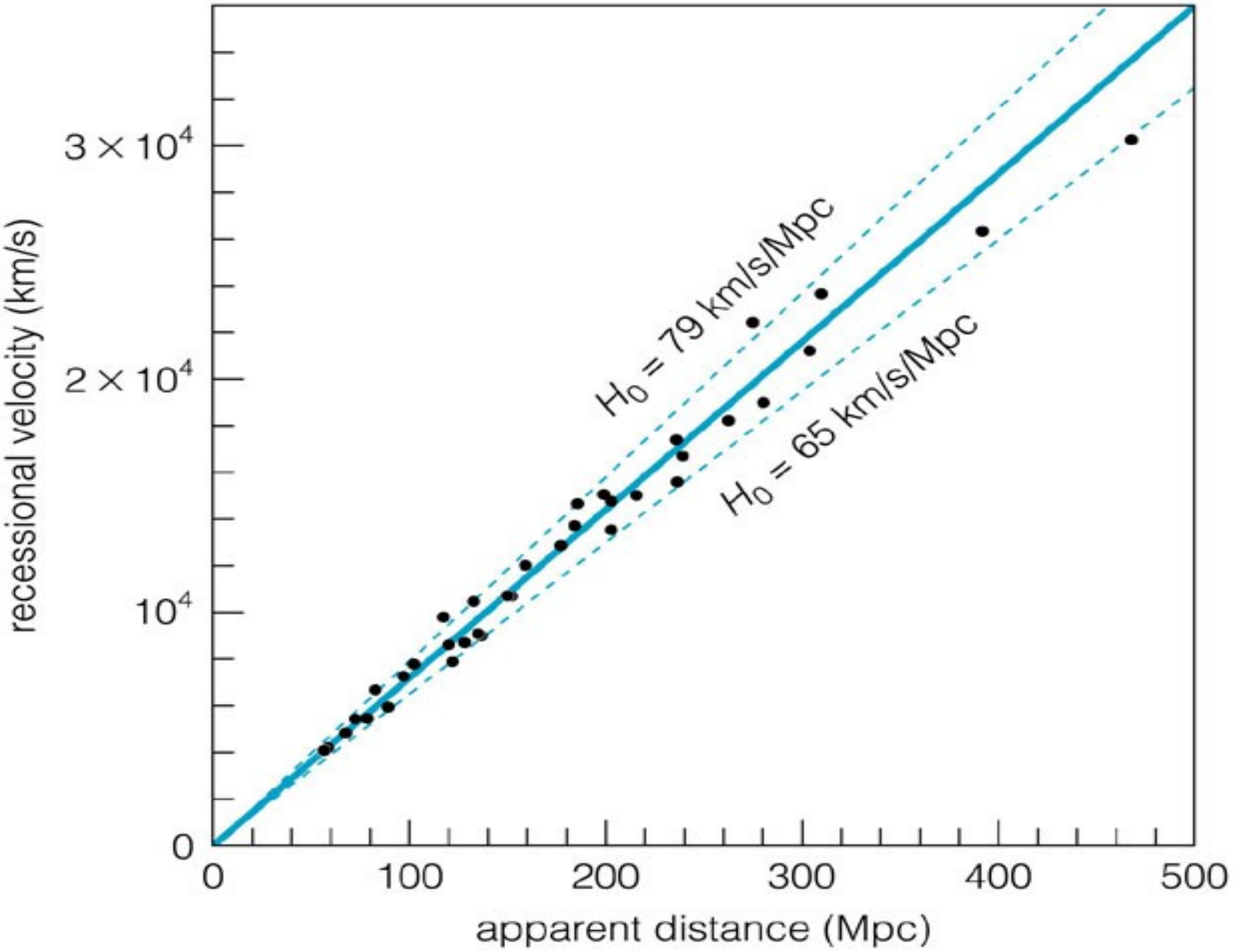
Comparing spectral (absorption/emission) lines to those of a lab reference (which isn't moving).

We talked about this for stars. It was called radial velocity. It is just Doppler shift.


λ0
λ′
very distant galaxy
distant galaxy
nearby galaxy
star
laboratory reference
400
500
600
700
Wavelength (λ)

Hubble plotted galaxy redshifts against their distances.

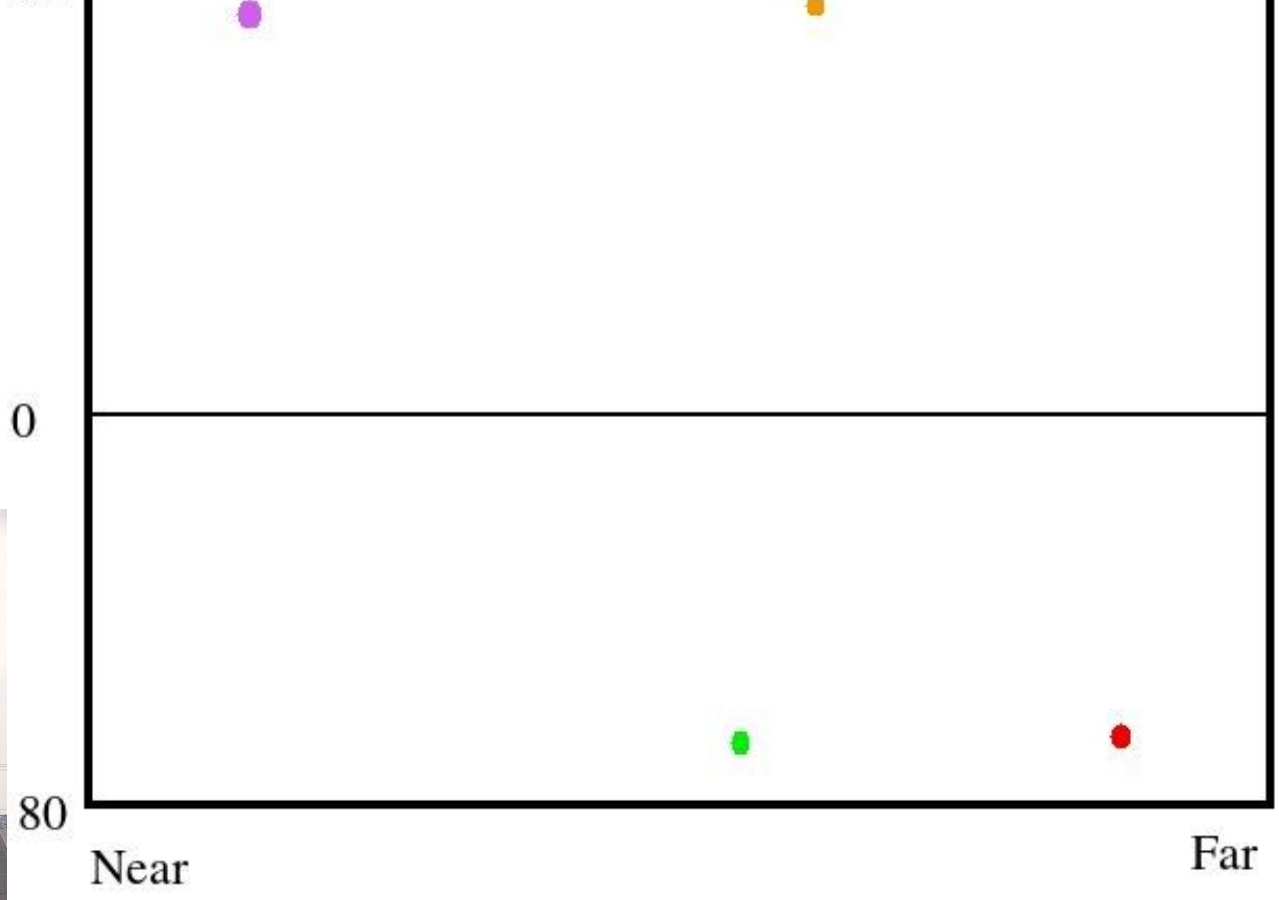
These are not random!



What are the speeds of the different cars?

Only consider towards or away from us (Doppler)

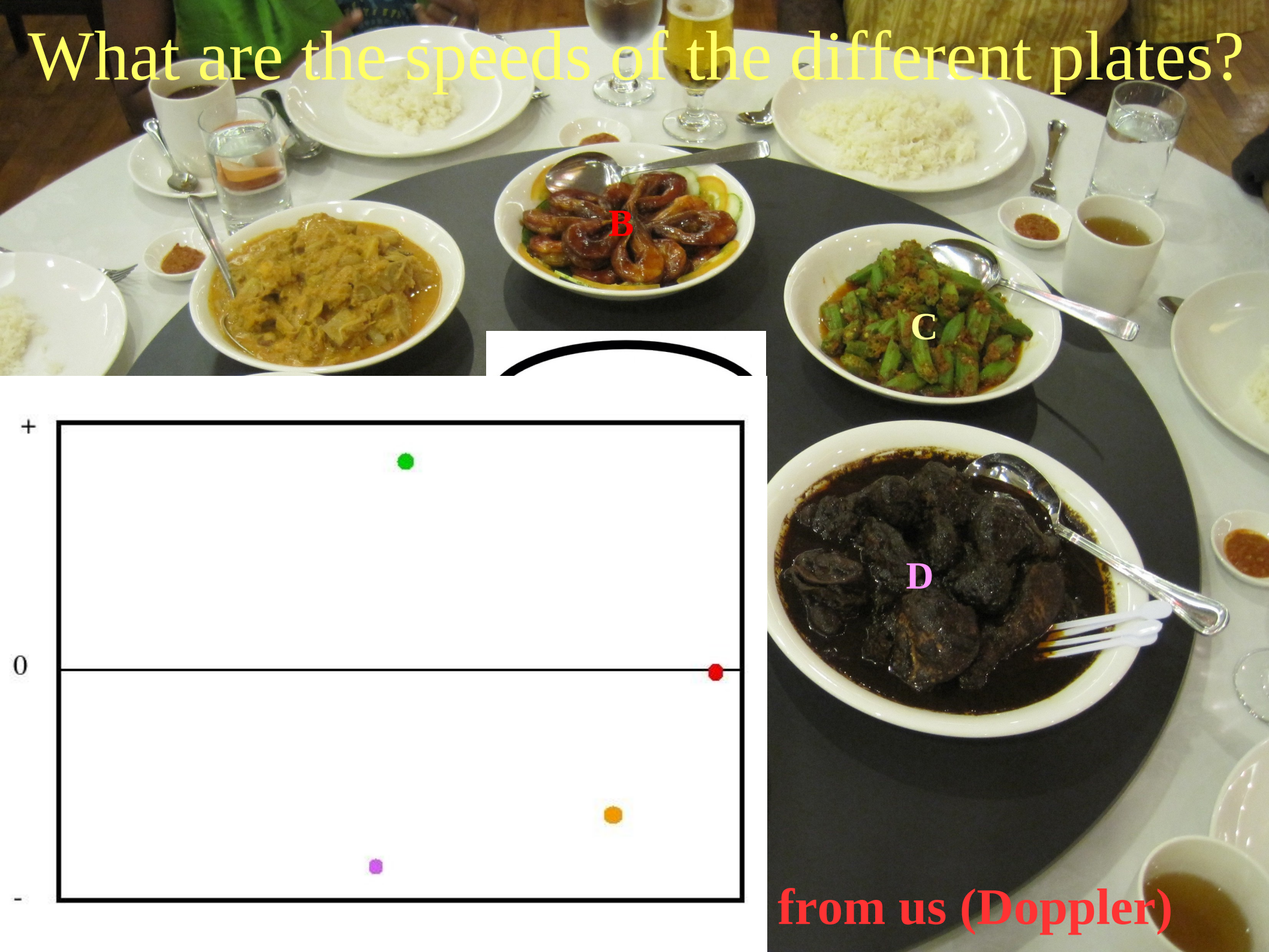
What are the speeds of the different cars?



What are the speeds of the different plates?

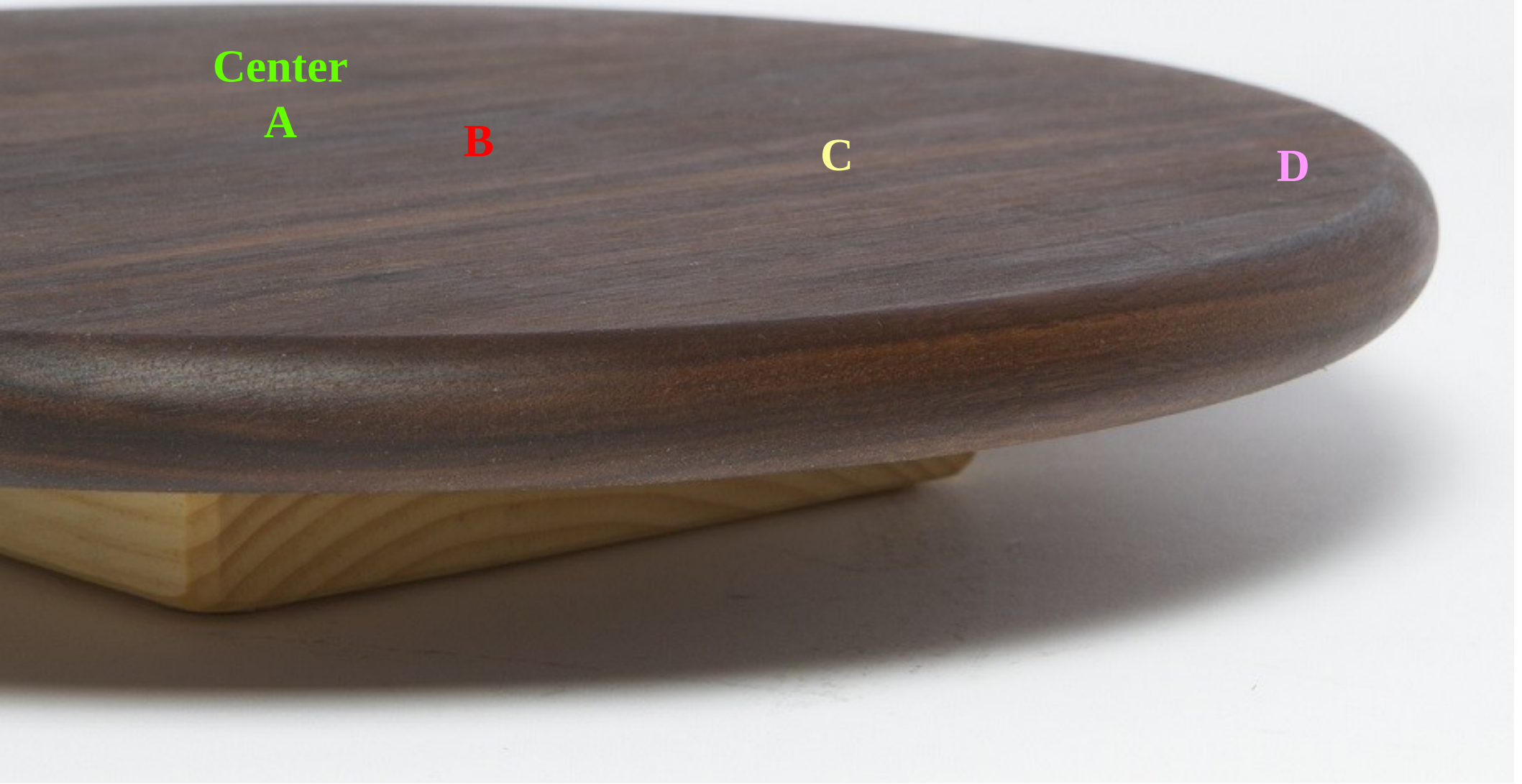
Only consider towards or away from us (Doppler)

What are the speeds of the different plates?



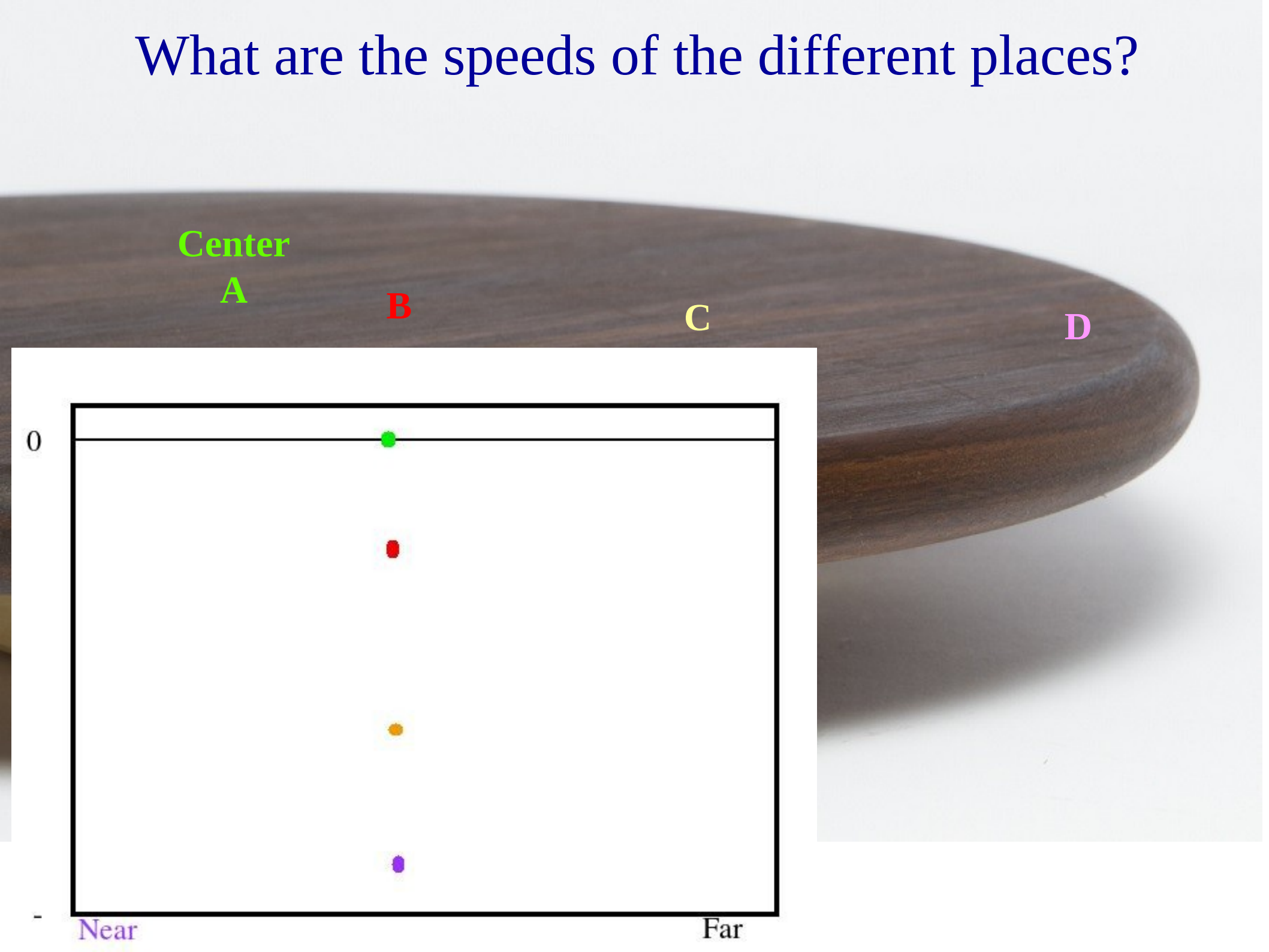
from us (Doppler)

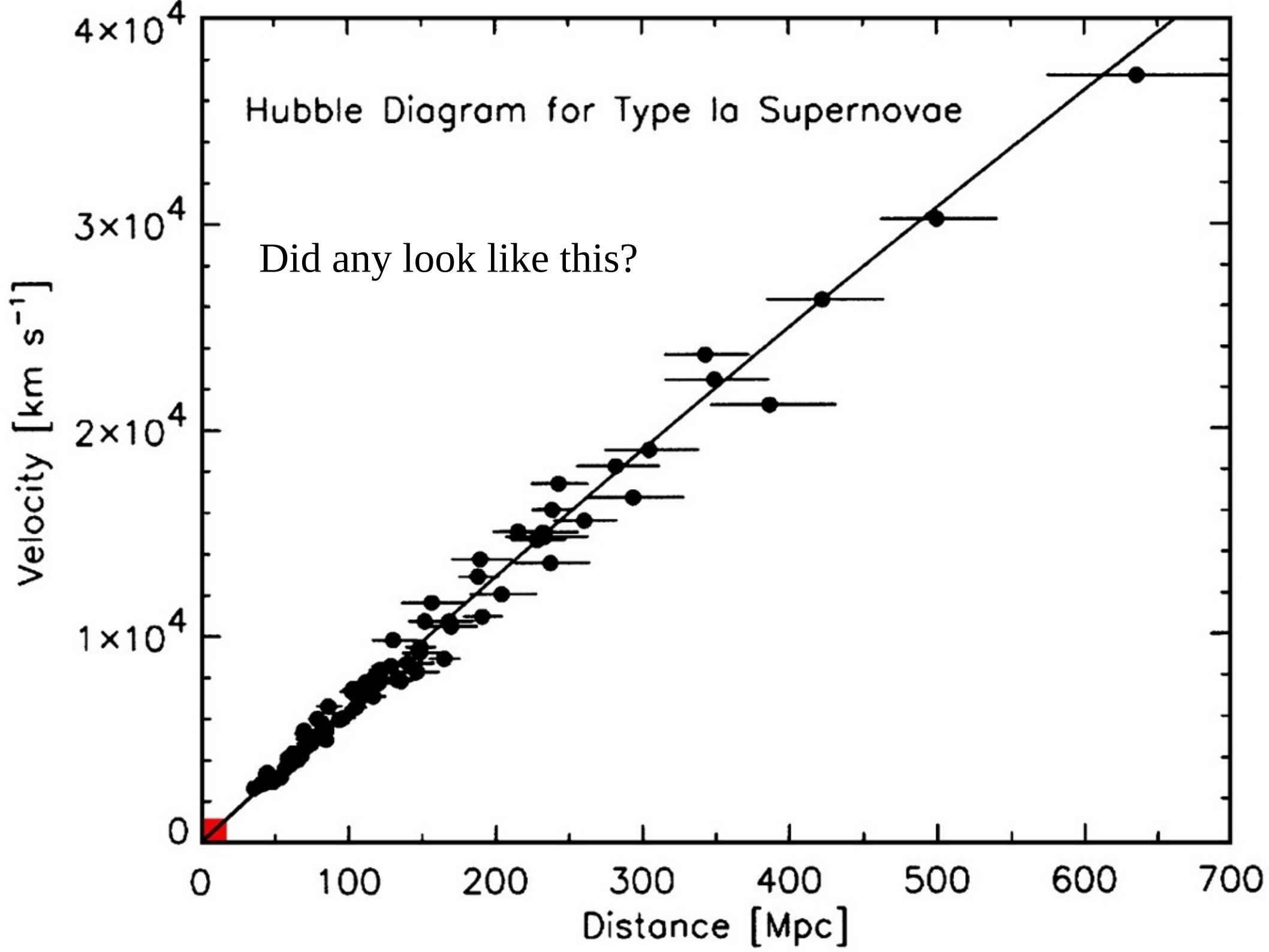
What are the speeds of the different places?



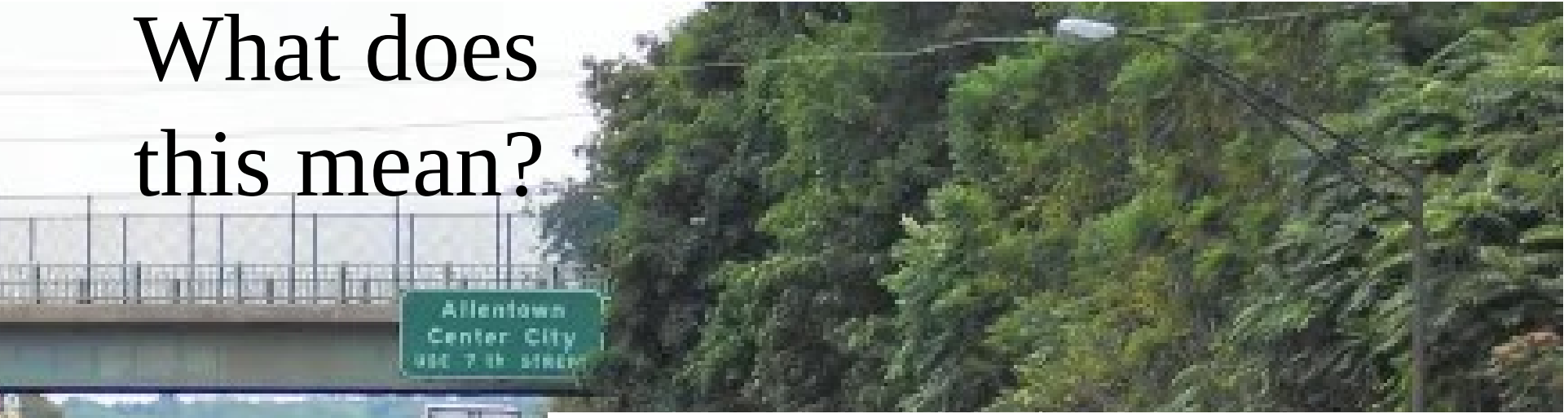
Only consider towards or away from us (Doppler)

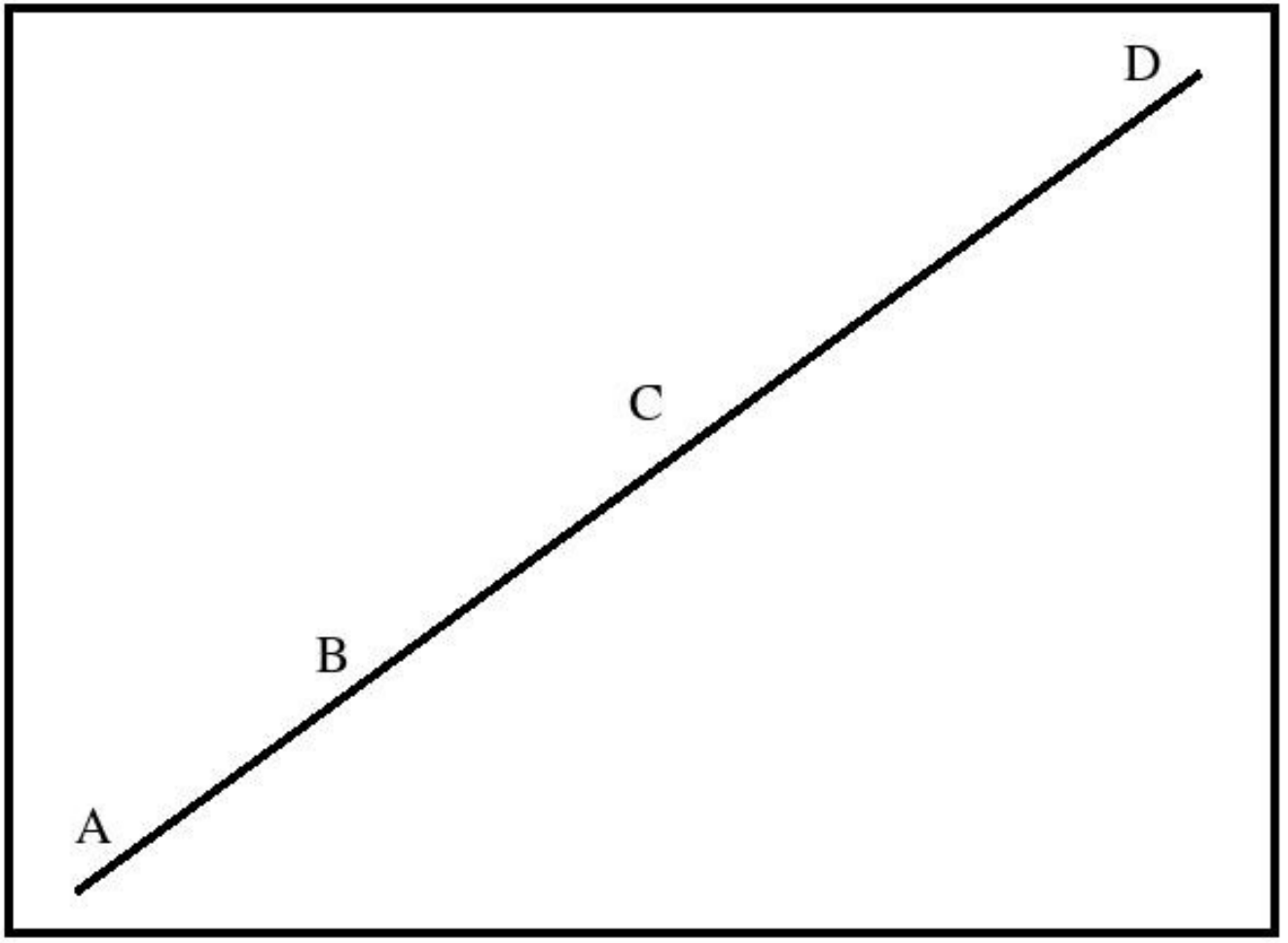
What are the speeds of the different places?



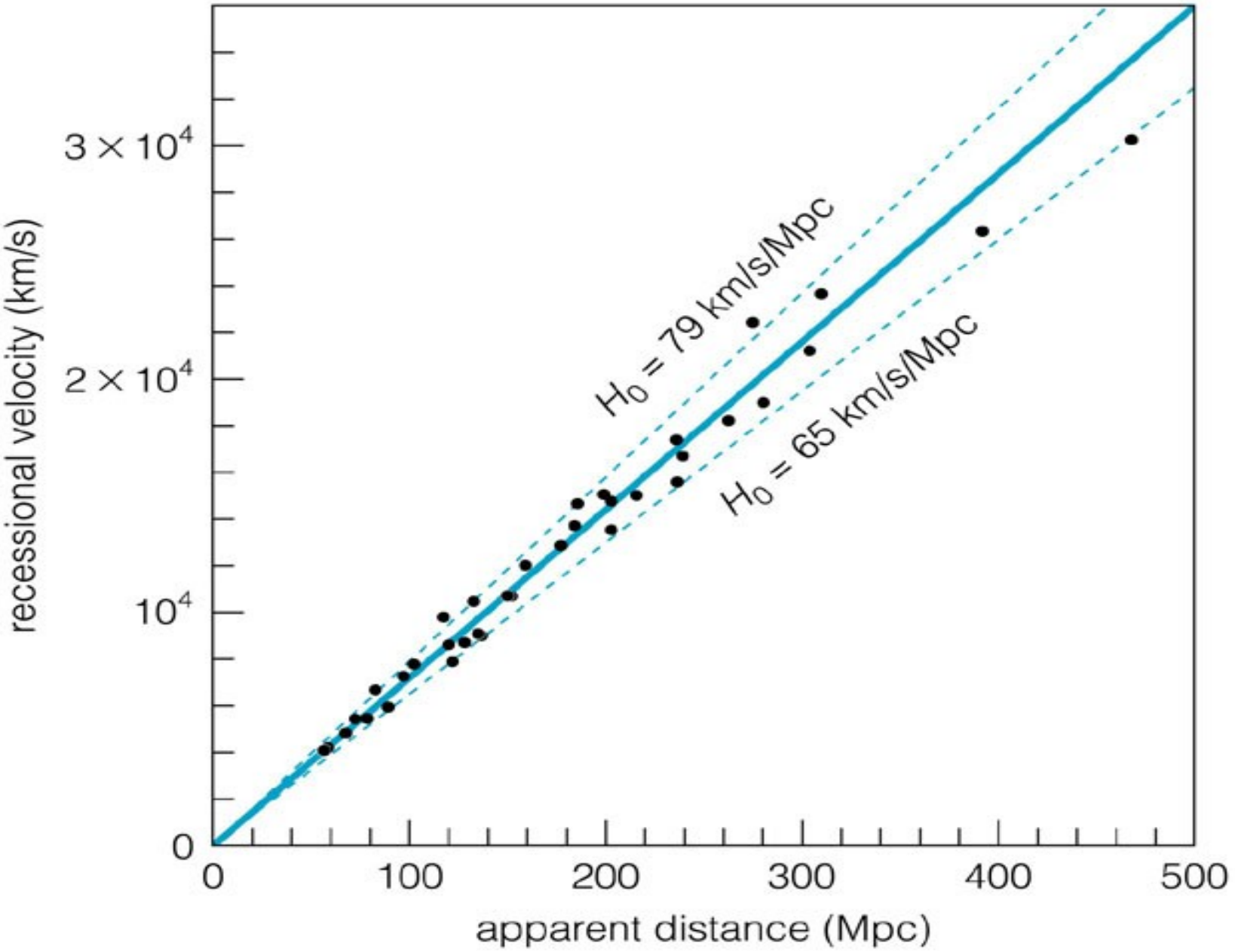

Hubble Diagram for Type Ia Supernovae
Did any look like this?
Velocity [km s^{-1}]
4×10^4
3×10^4
2×10^4
1×10^4
0
0
100
200
300
400
500
600
700
Distance [Mpc]

What does this mean?

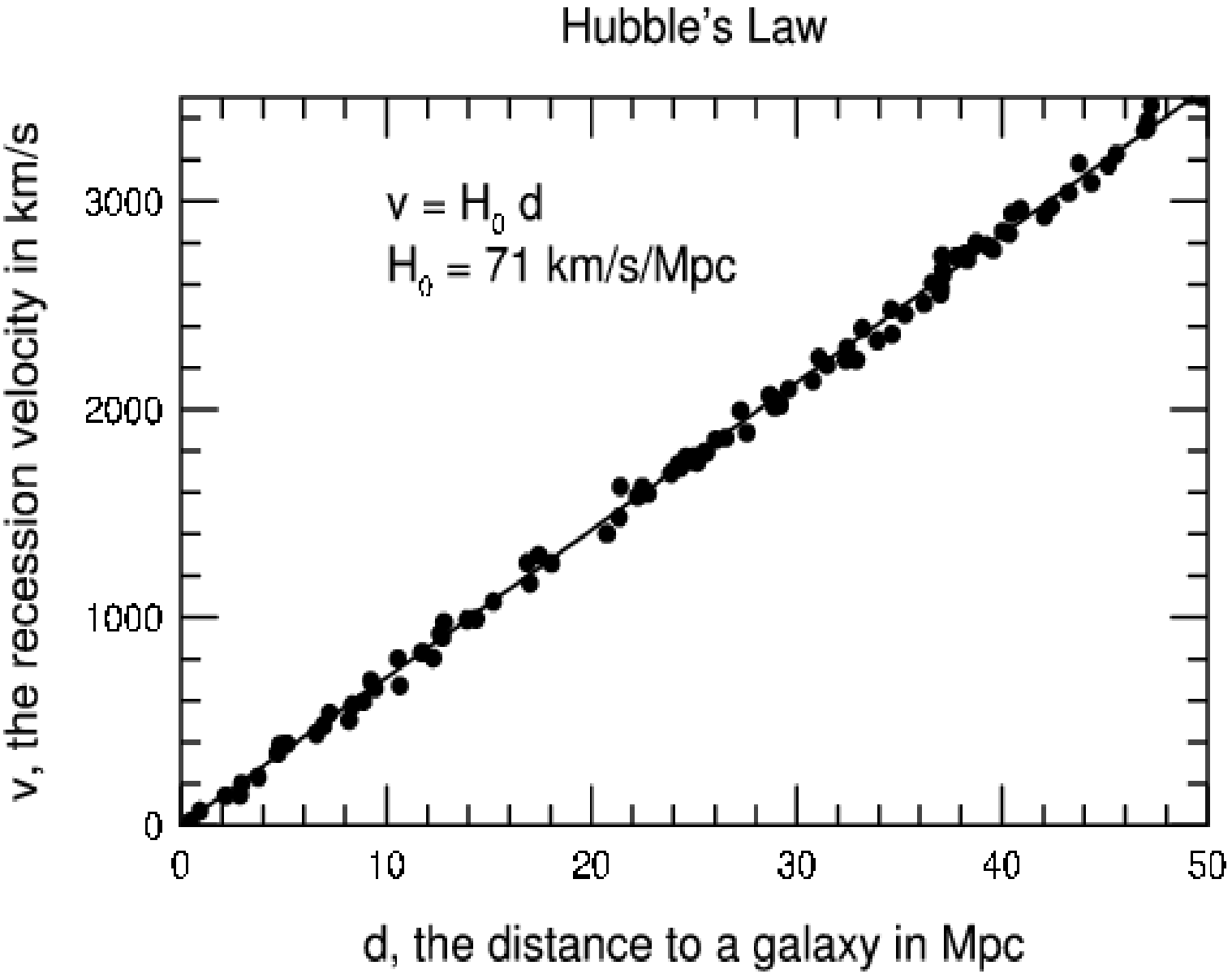




Galaxies (beyond our local group/cluster) are moving away from us, with a relationship!



No matter where you look, galaxies fall onto this line!



The slope is Hubble's Constant.

$$H_o = v/D$$

redshift velocity divided by distance.

The slope is Hubble's Constant.

$$H_o = v/D$$

redshift velocity divided by distance.

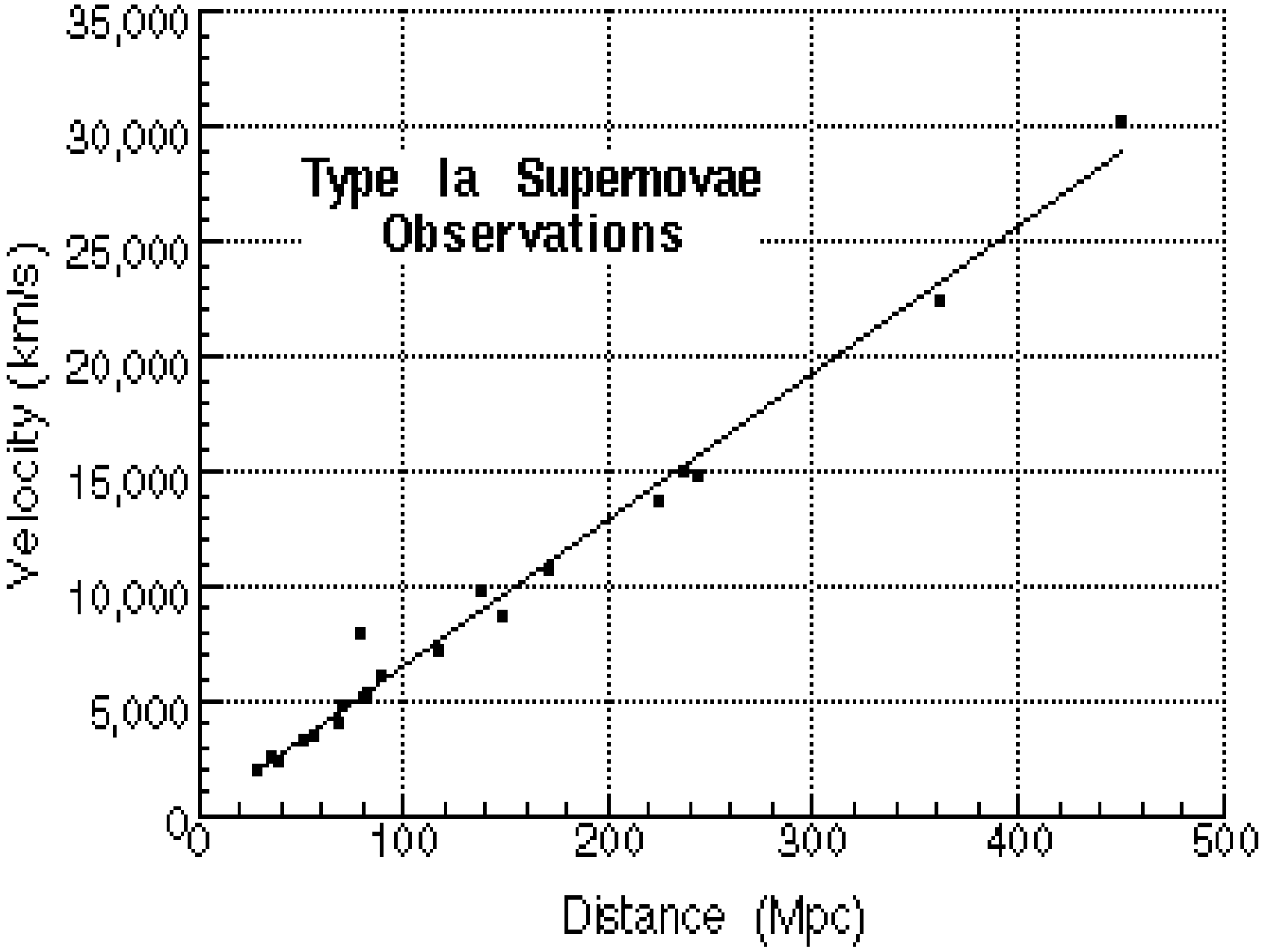
This value has been measured:

H_o=73.8 +/- 2.4 km/s/Mpc

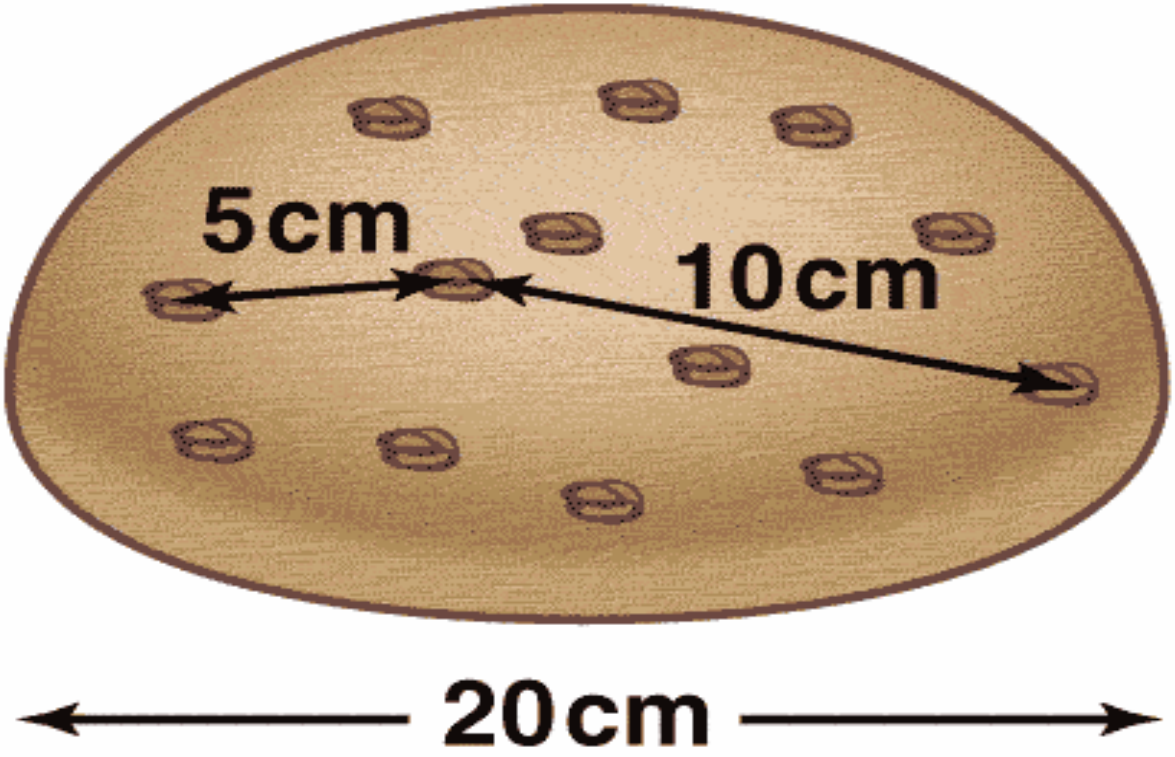
Quiz 14b: Classify this galaxy.

A) Elliptical
B) Spiral
C) Barred spiral
D) Irregular
E) None of those.

Why does this relationship exist?



It indicates the Universe is expanding!



Imagine that the expanding Universe is a loaf of raisin bread. When baked in the oven, the bread expands, but the raisins do not. The bread represents the space in the Universe, and the raisins represent galaxies and other astronomical objects . While the bread itself undergoes a large change in structure, the raisins themselves stay the same.

MAP990404

Expanding Universe

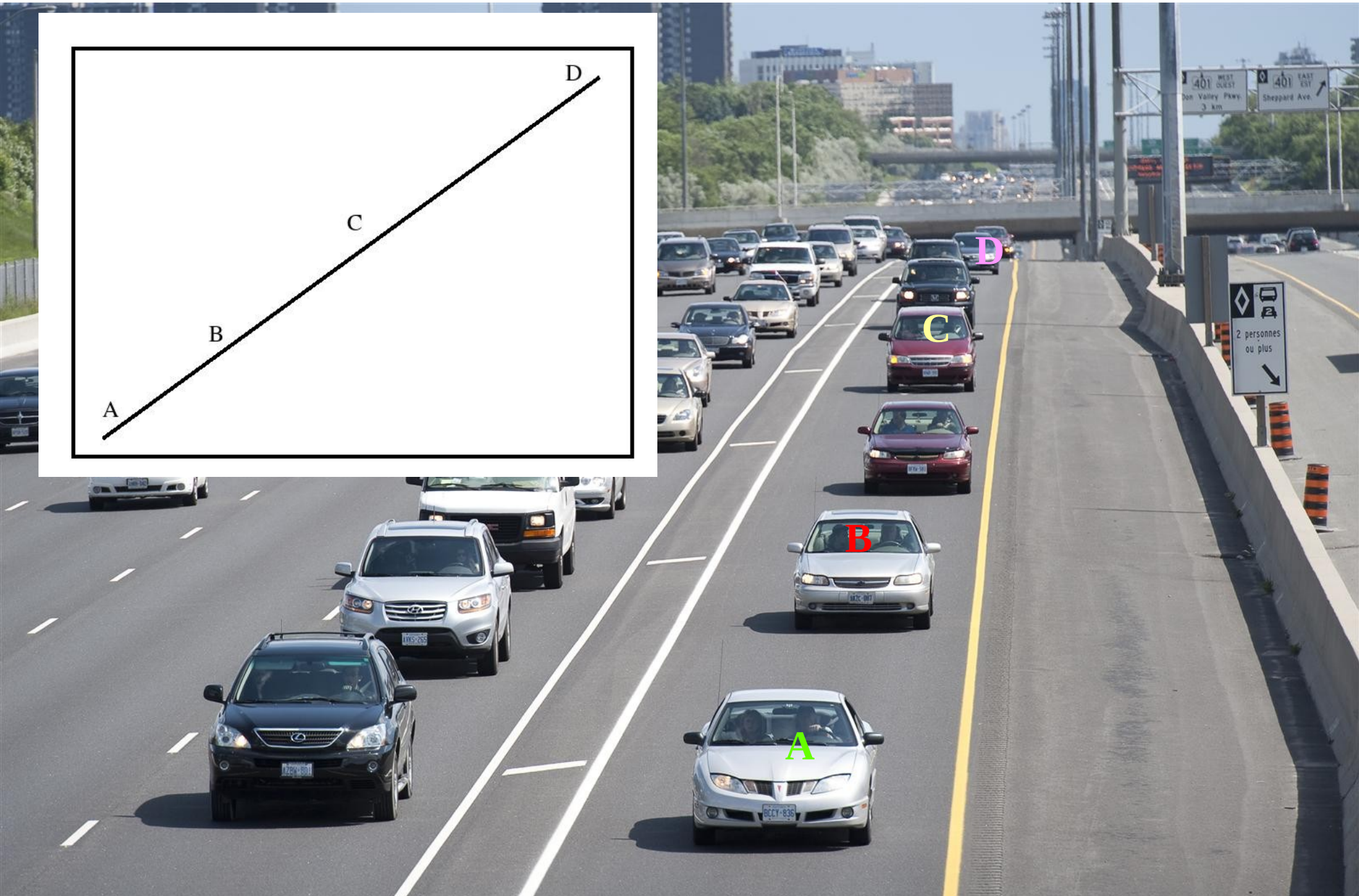
As we look farther away from us, galaxies are moving away from us faster.

Expanding Universe

What if we run the clock backwards?

(like our last car example)

Expanding Universe: What if we run the clock backwards?



Expanding Universe

What if we run the clock backwards?

Sometime in the past, the galaxies were at the same spot, at the same time!

What does this mean?