A “Model” in Science

Something made to be *like* some part of the real world in a particular way.

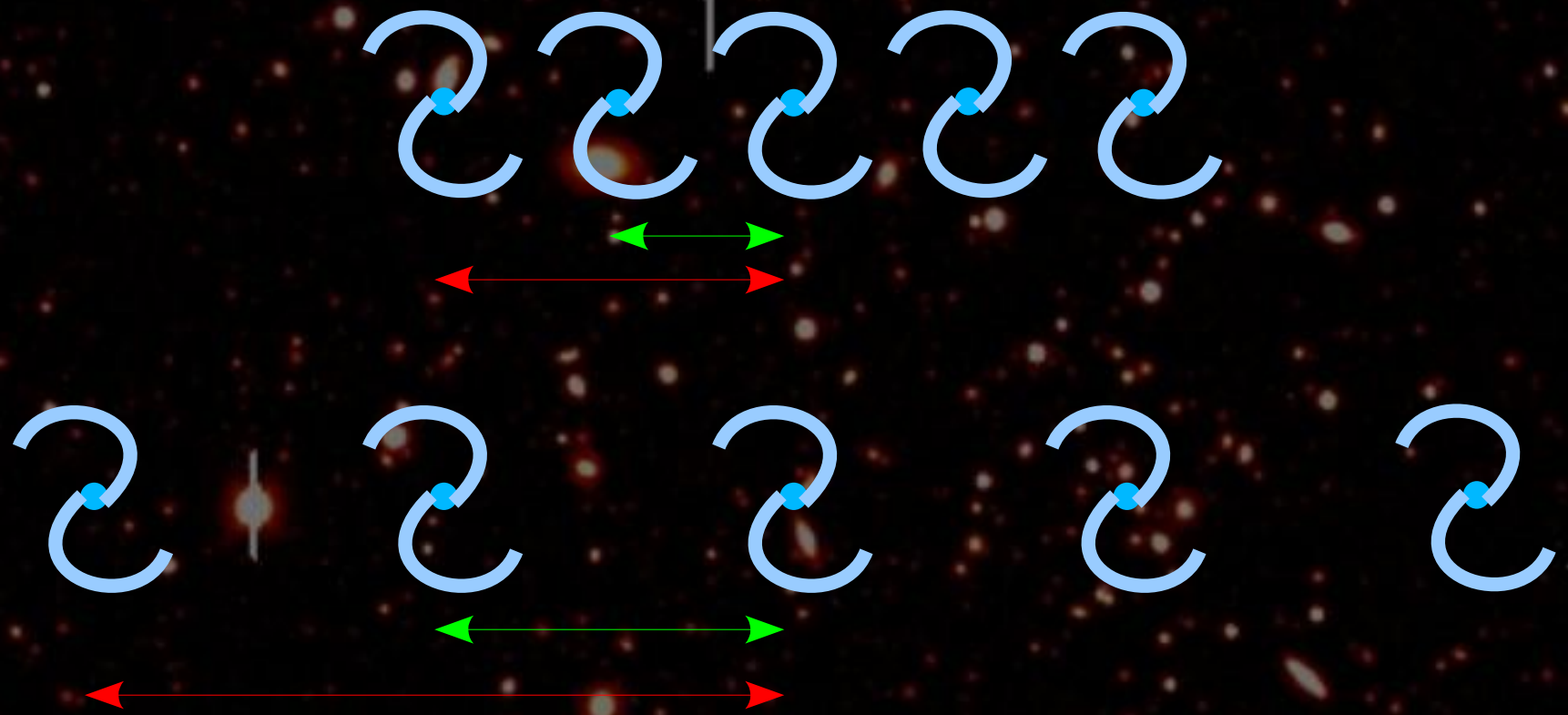
Studying a good model can help us learn something about the natural world.

A “scale model” is a smaller (or bigger) picture or sculpture of something that shows us what that thing looks like, maybe also on the inside.

A “mathematical model” is all equations and numbers, but allows us to calculate things about something.

There are other kinds of models; we can make a model of the whole Universe with rubber bands and paper clips....

A "uniform" expansion



$$\frac{\text{Change in Distance}}{\text{Distance}} = \text{Constant}$$

The greater the initial distance,
the greater the change in distance.

With galaxies, how can we measure “change in distance”?

Final Distance = 110 miles
Start Distance = 60 miles

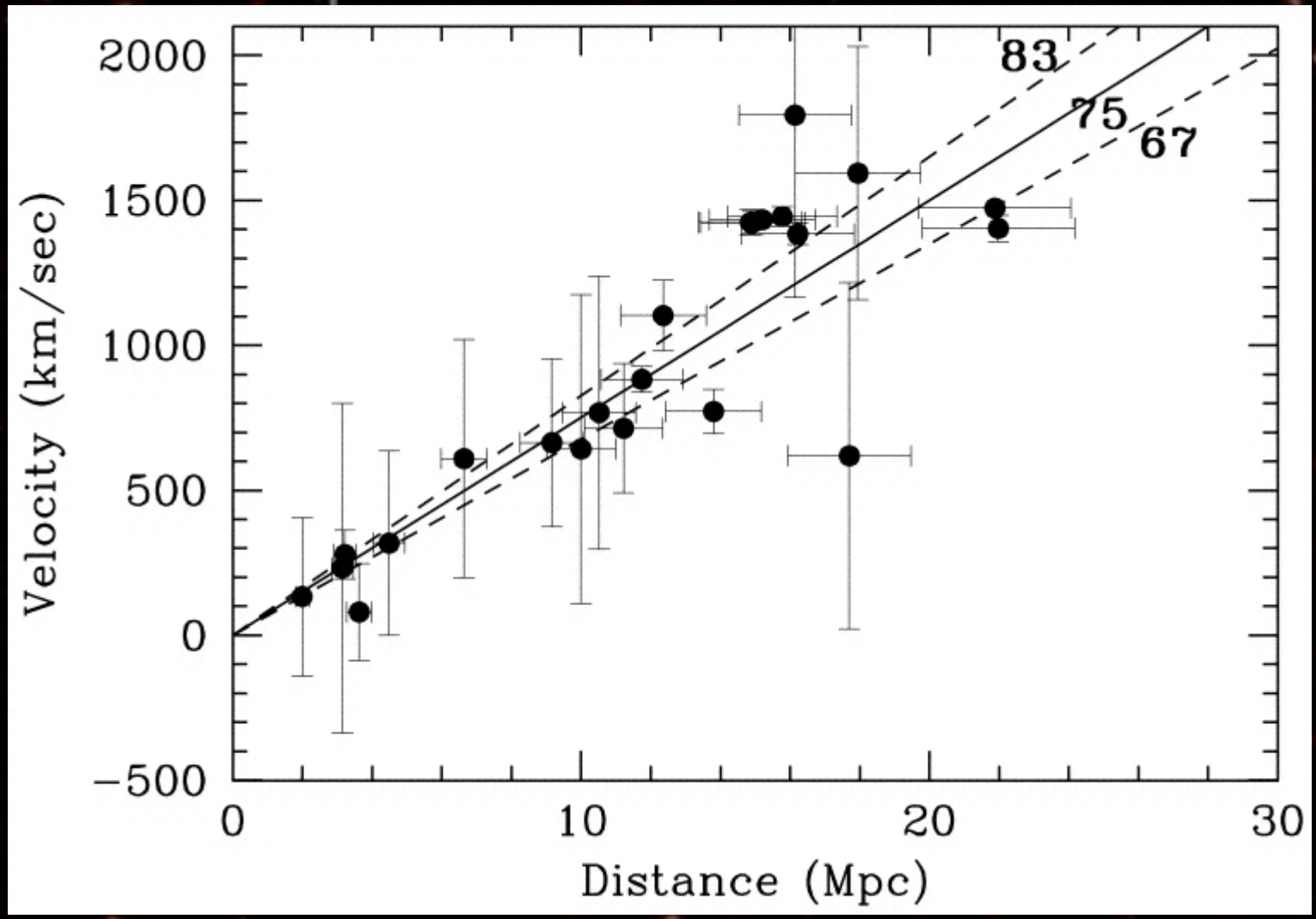
Change in Distance = 110 – 60 miles = 50 miles

Speed = 50 miles / 1 hour = 50 miles per hour

$$\text{Speed} = \frac{\text{Change in Distance}}{\text{Time}}$$

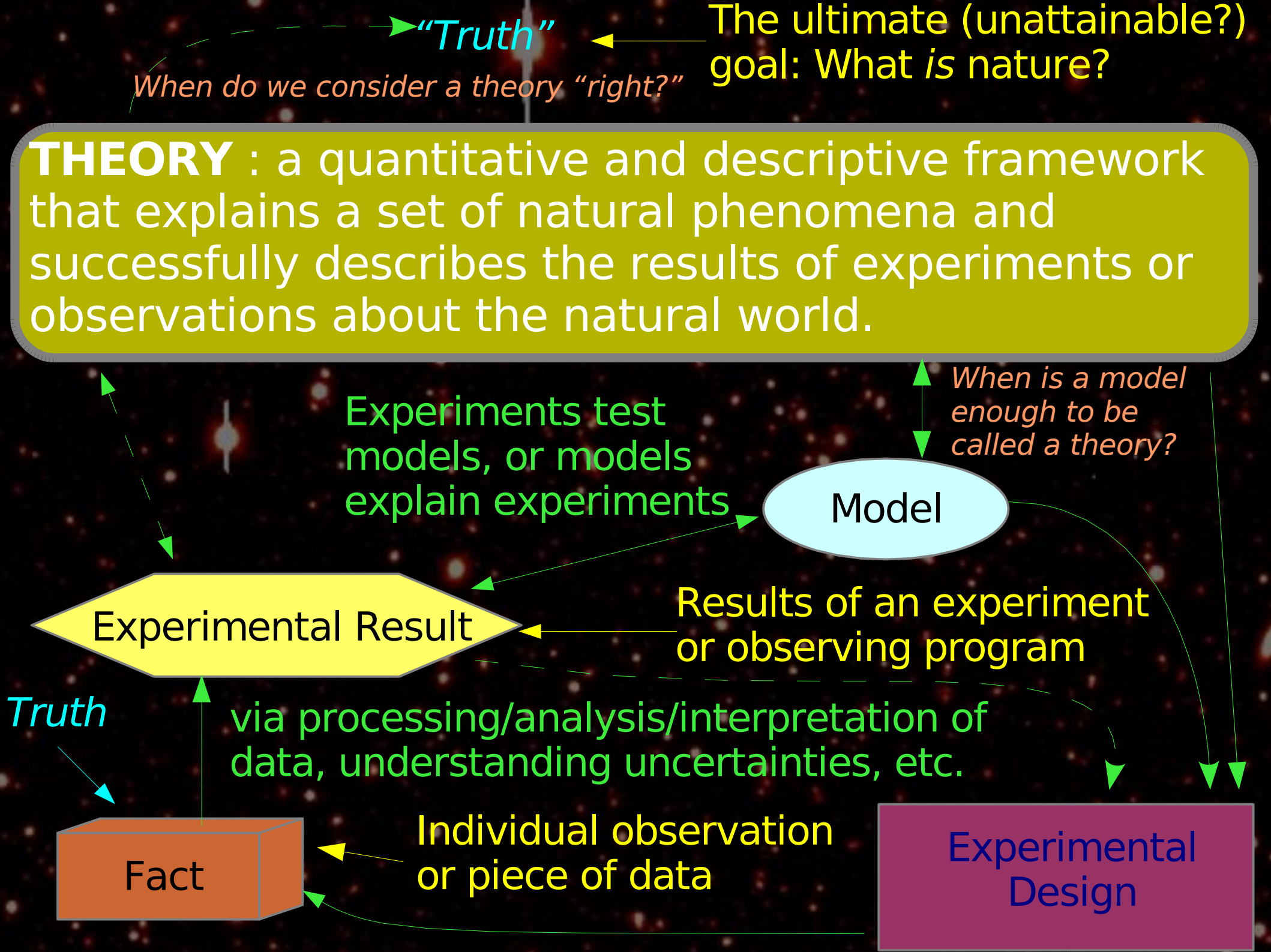
The “Hubble Diagram” of Galaxies Moving Away From Us

Chagne in Distance
(in one second)



Distance

Note: the next few slides can be used if there is extra time, or if questions come up that could benefit from them.


"Truth"
The ultimate (unattainable?) goal: What *is* nature?
When do we consider a theory "right?"
THEORY : a quantitative and descriptive framework that explains a set of natural phenomena and successfully describes the results of experiments or observations about the natural world.
When is a model enough to be called a theory?
Experiments test models, or models explain experiments
Model
Experimental Result
Results of an experiment or observing program
Truth
via processing/analysis/interpretation of data, understanding uncertainties, etc.
Fact
Individual observation or piece of data
Experimental Design

"Theoretically Impossible"

= not possible *in principle* given our best current understanding of nature

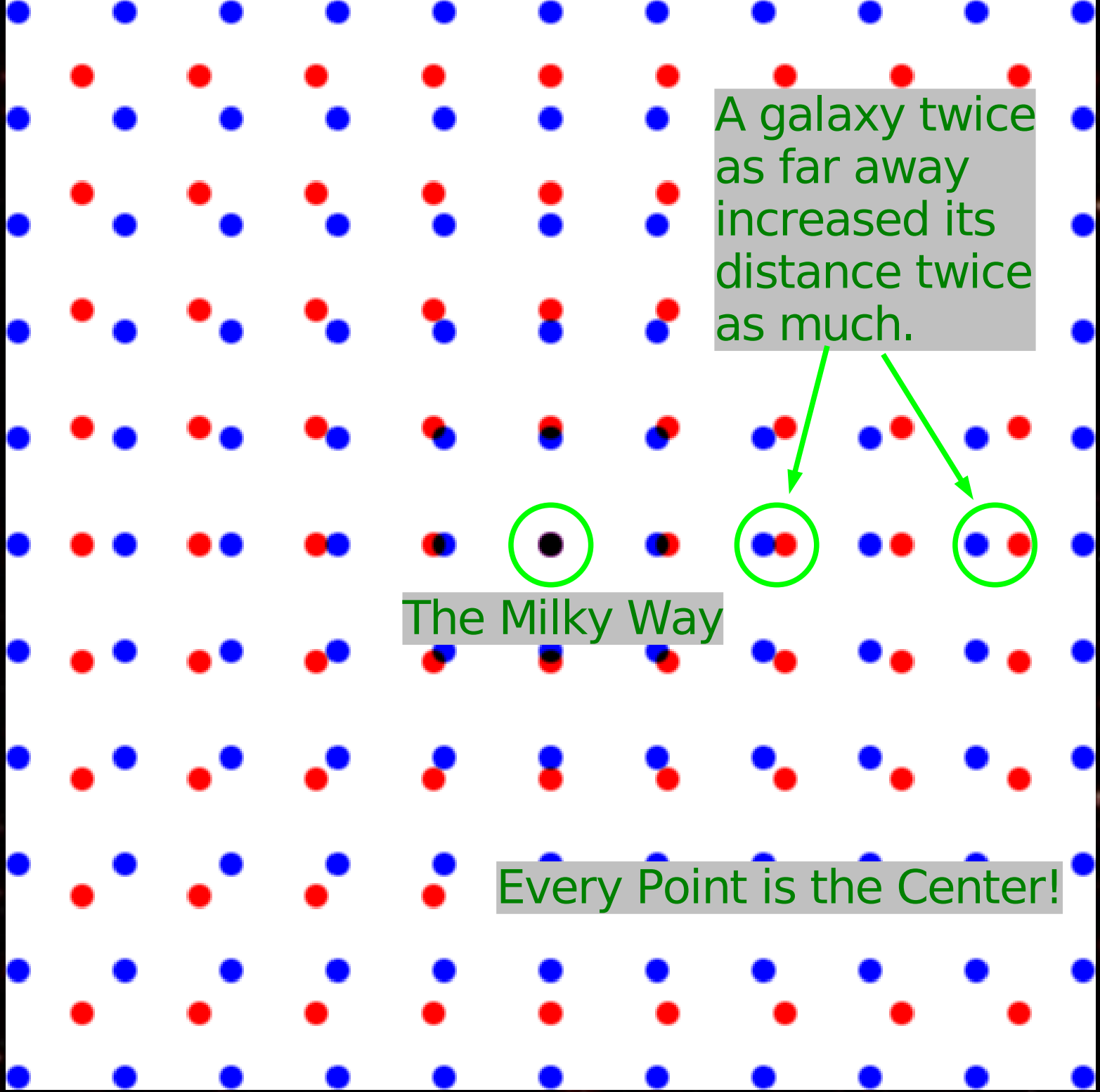
This is a stronger statement than "you think it can't be done".

Example : for a red light to look green, you must be going 100 million mph. This is impossible for any car available right now... but is perfectly possible in principle.

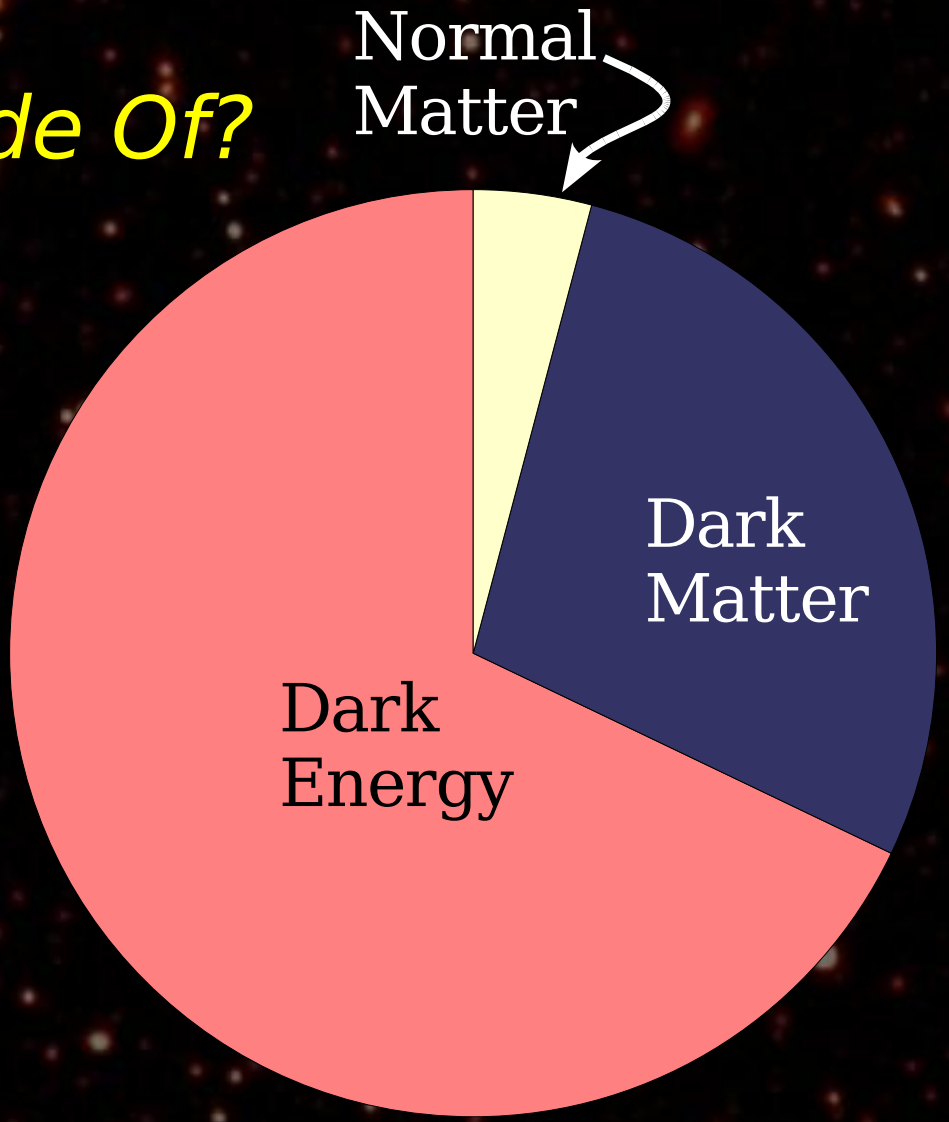
It is *theoretically impossible* for anything to go faster than 670 million mph, the speed of light.

(See also "slides on science & religion")

Movies showing the expansion of the Universe as a 2d model.


A galaxy twice as far away increased its distance twice as much.
The Milky Way
Every Point is the Center!

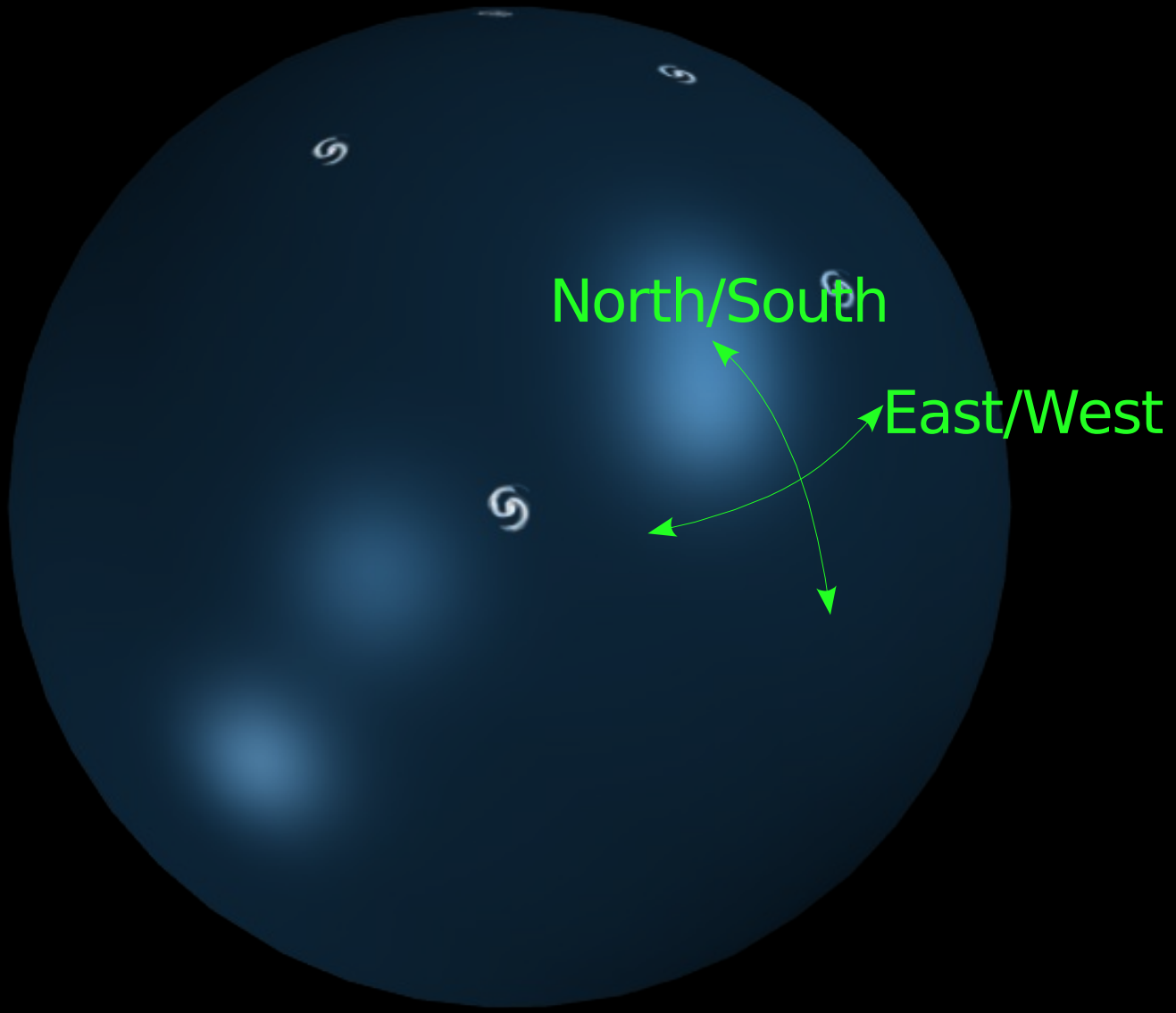
What is the Universe Made Of?

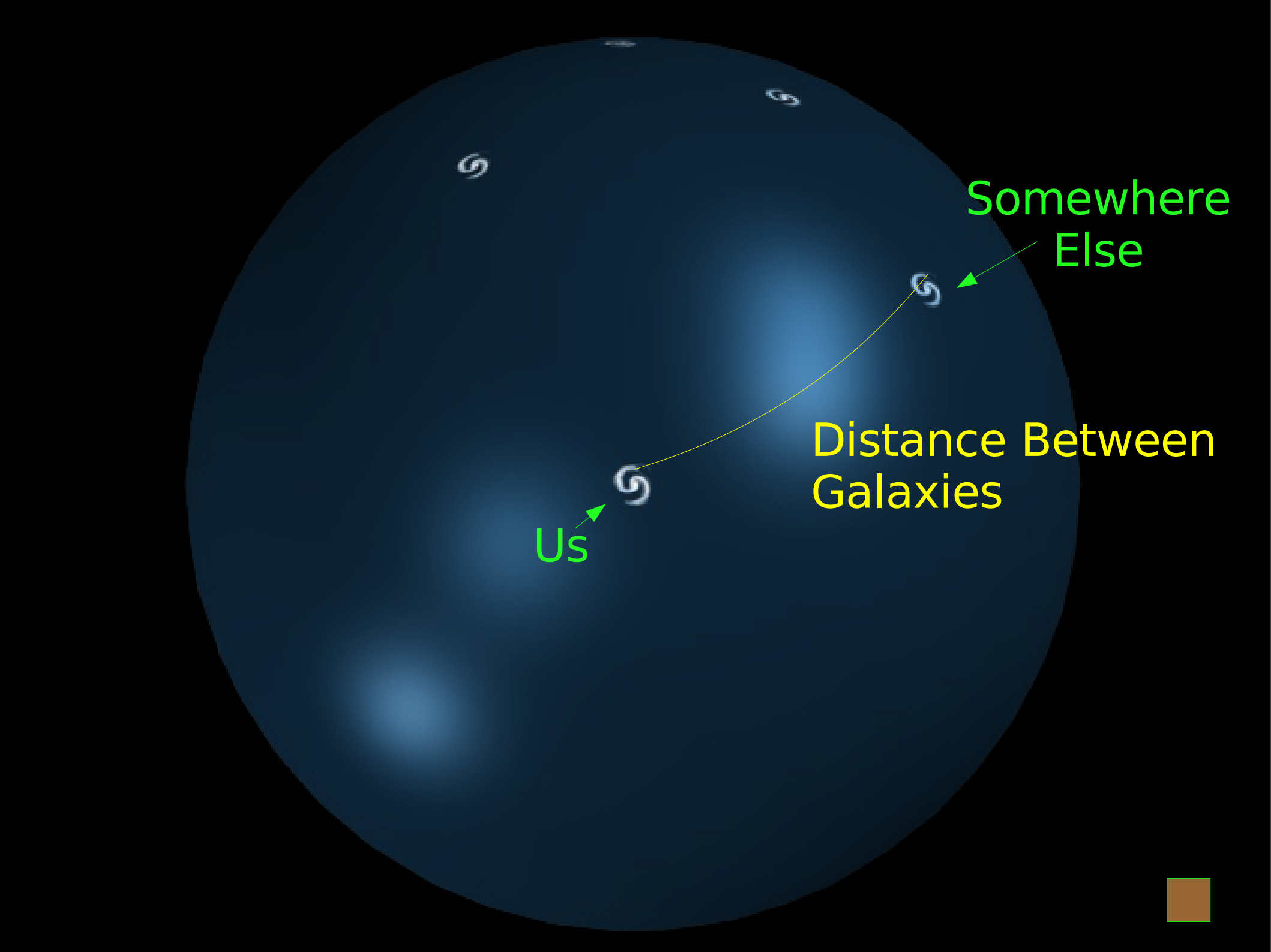


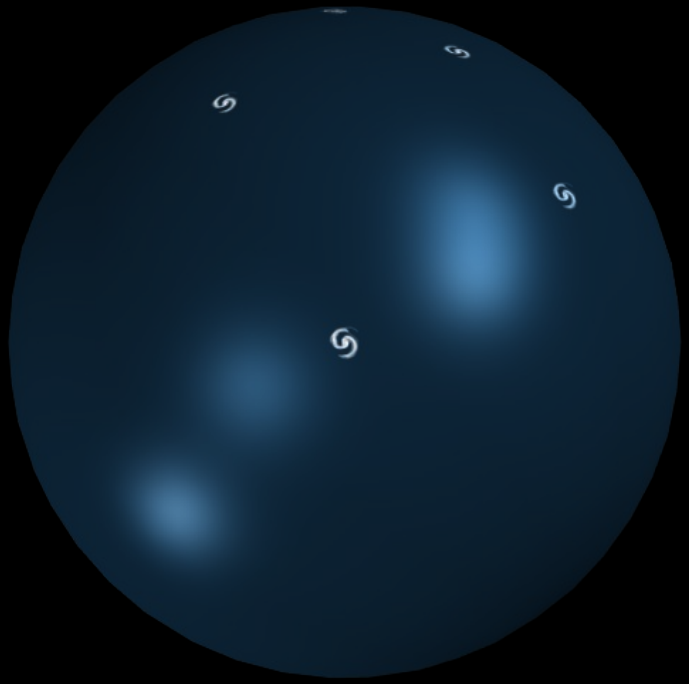
- Normal Matter: Stars, Nebulae, You
- Dark Matter: Strange stuff with normal gravity.
- Dark Energy: Stranger stuff with strange gravity that makes the expansion speed up.

Note: the remaining slides are more advanced, and should probably only be used in presentations to more advanced (high school?) students or to teachers.

A model 2-d closed Universe: the surface of a sphere



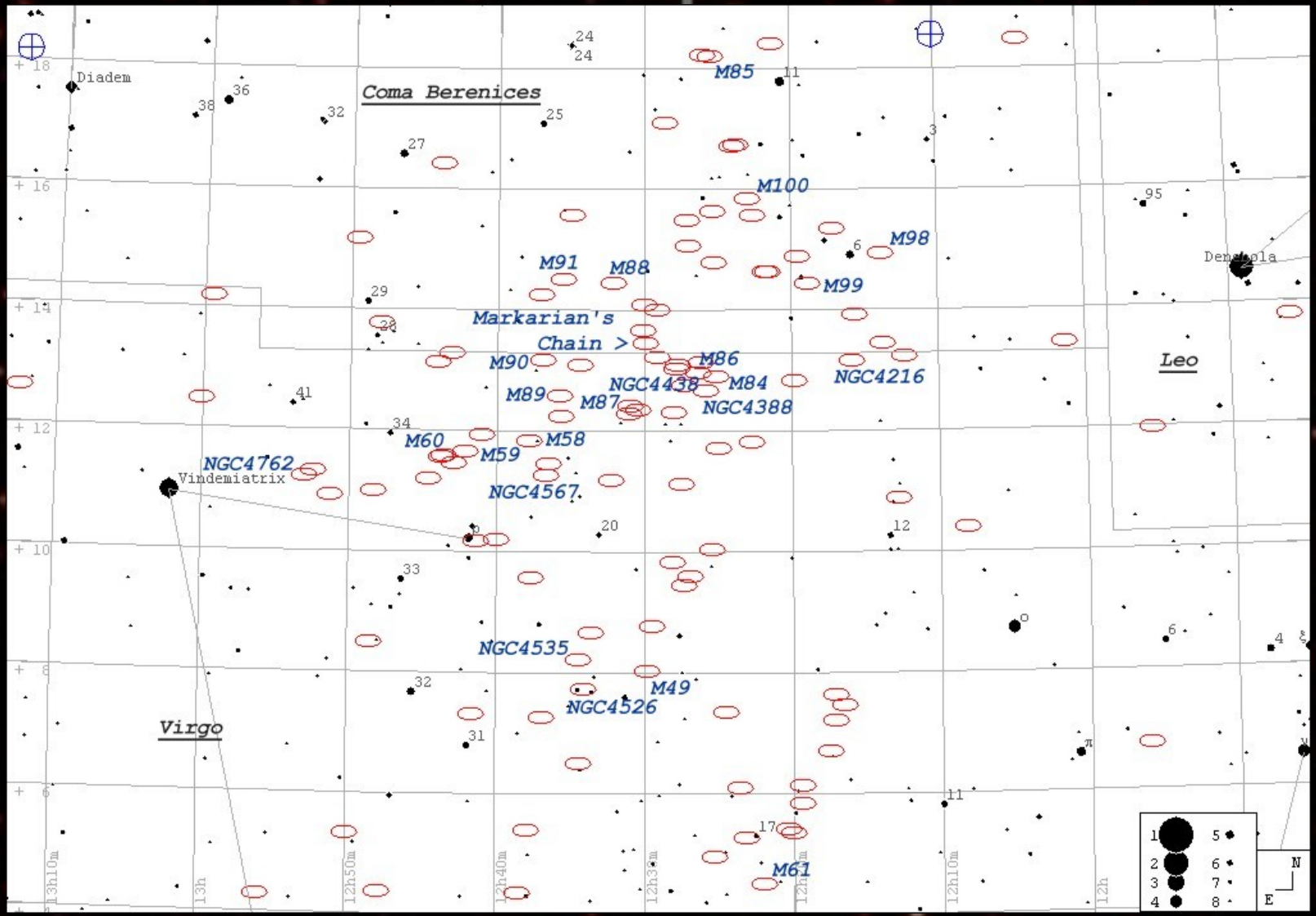

Somewhere
Else
Distance Between
Galaxies
Us



Points to notice

- As the Universe expands, galaxies get farther apart, but...
- ...galaxies are *not* moving *through space* **
- Galaxies *don't* expand themselves
- A second galaxy that is farther away from a first galaxy *looks like* it's moving faster than one that's closer.
- This works just like paper clips on a rubber band.

How Fast Is The Universe Expanding?



The Virgo Cluster

Map by Jan Wisniewski

Distance today: 20 Mpc (million parsecs)

Distance in 100 years: 20 Mpc + 1 ten millionth of a Mpc.

“Look-back” time to Virgo Cluster:

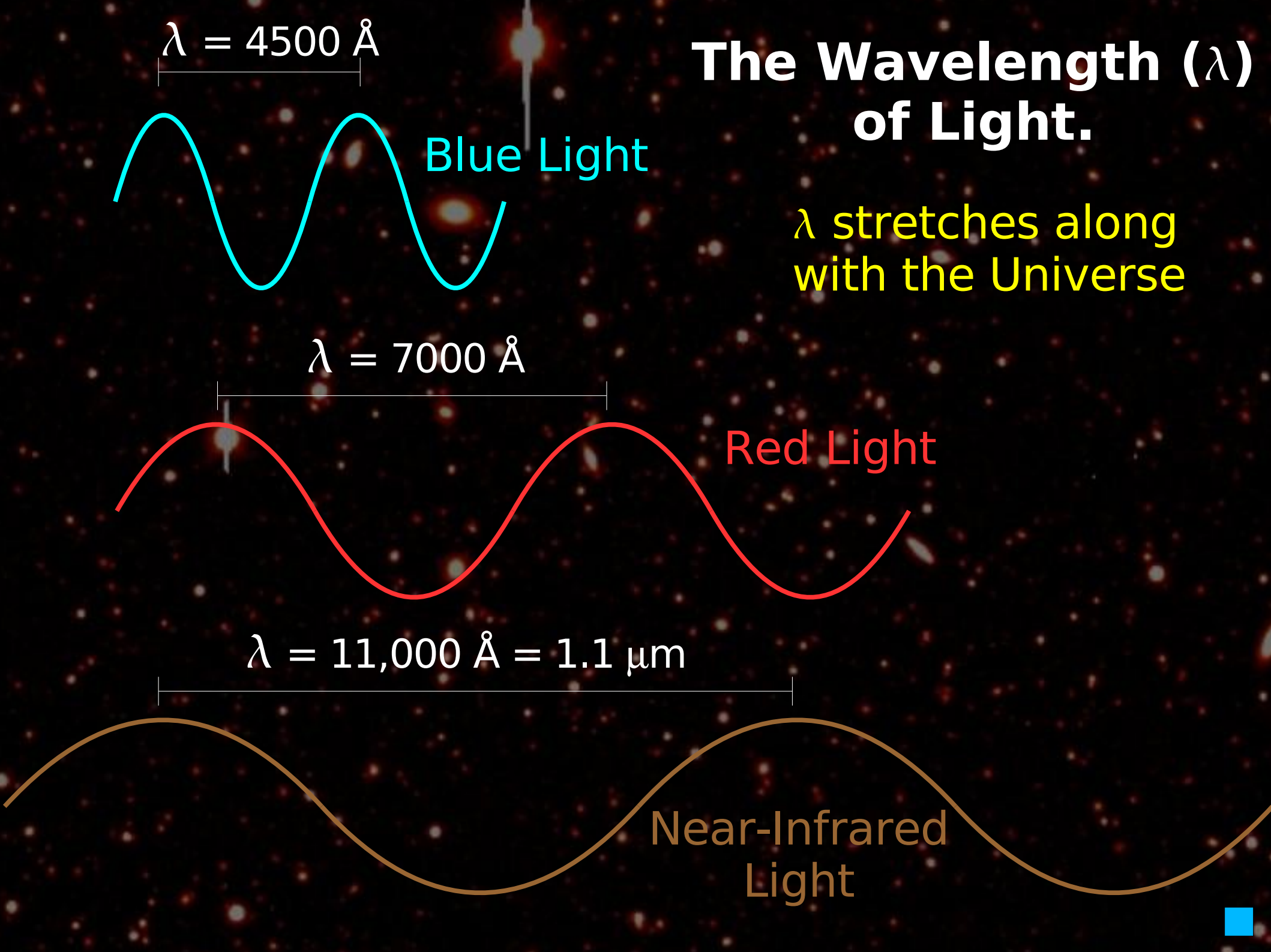
1 parsec = 3.26 light-years

Light goes 1 light-year in one year (surprise!)

20 million parsecs means we see the Virgo clutser as it was 65 million years ago.

Can we find something that has expanded along with the Universe over that time????

Yes! Light!


λ = 4500 Å
Blue Light
The Wavelength (λ) of Light.
λ stretches along with the Universe
λ = 7000 Å
Red Light
λ = 11,000 Å = 1.1 μm
Near-Infrared Light

REDSHIFT

$$\frac{\text{Wavelength Now}}{\text{Wavelength when light was emitted}}$$

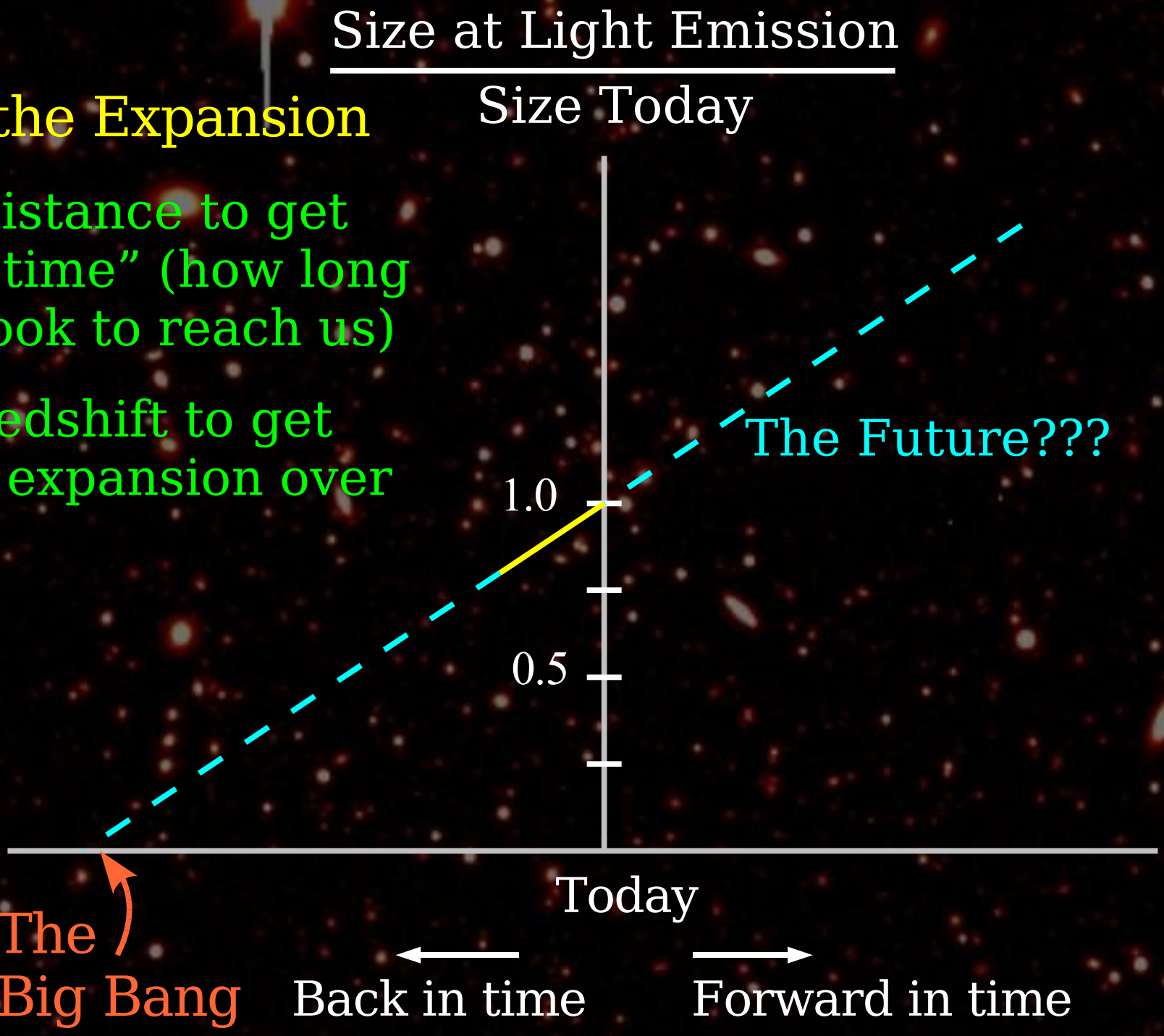
Amount of Universe Expansion:

$$\frac{\text{Distance Now}}{\text{Distance when light was emitted}}$$

Cosmological Redshift – the two are the same!

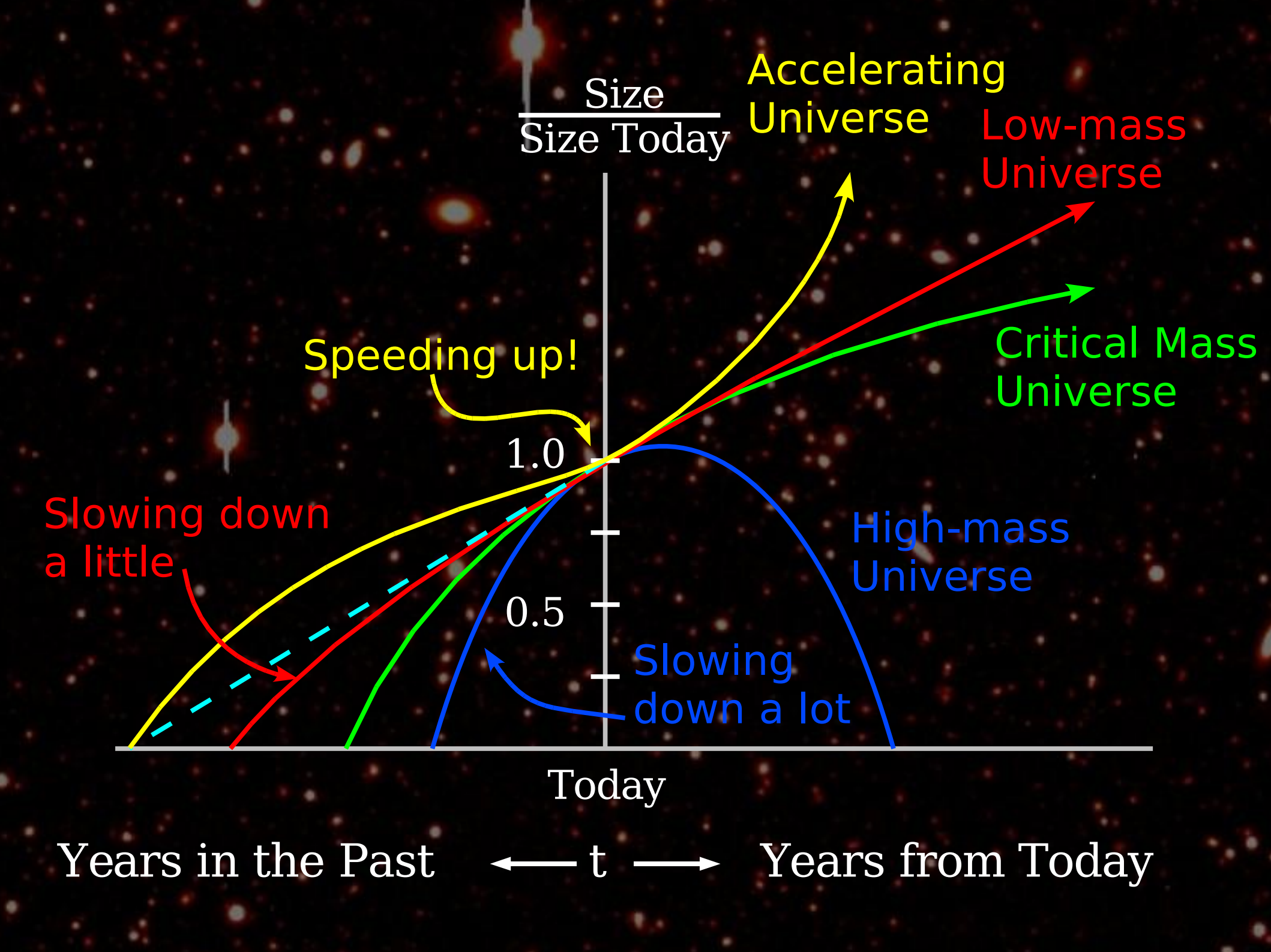
Measuring the Expansion

- Measure distance to get "lookback time" (how long the light took to reach us)
- Measure redshift to get amount of expansion over that time.



Lookback Times

Object	Lookback Time
Sun	8 minutes
Alpha Centauri	4 years
Andromeda Galaxy	2 million years
Seyfert Galaxy NGC1068	16 million years
Quasar 3C273 at z=0.158	2 billion years
Galaxy at who emitted light at half the wavelength we see	7 billion years
Age of Universe	13 billion years


Size
Size Today
Accelerating
Universe
Low-mass
Universe
Critical Mass
Universe
Speeding up!
1.0
Slowing down
a little
High-mass
Universe
0.5
Slowing
down a lot
Today
Years in the Past
t
Years from Today