

A Uniform Expansion

$$\frac{\Delta d}{d} = \frac{\Delta t}{t_H}$$

d Distance to object now

Δd Change in distance to object during time Δt

t_H Expansion timescale

$t_H =$ age of the Universe *if the expansion rate has always been constant*

Today's best value : $t_H = 13.8 \pm 0.6$ Gyr

(Spergel et al., 2006, astro-ph/0603449)

$$\frac{\Delta d}{d} = \frac{\Delta t}{t_H}$$

A Universe right now has expansion timescale $t_H = 13.8$ Gyr. Assume the expansion rate has always been constant.

Galaxy A is twice as far away as Galaxy B. How will t_H as measured for Galaxy A compare to t_H as measured from for Galaxy B? (Assume that Galaxy A is no more than, say, a hundred million light-years away.)

A $t_H(\text{A}) = \frac{1}{4} t_H(\text{B})$

B $t_H(\text{A}) = \frac{1}{2} t_H(\text{B})$

C $t_H(\text{A}) = t_H(\text{B})$

D $t_H(\text{A}) = 2 t_H(\text{B})$

E $t_H(\text{A}) = 4 t_H(\text{B})$

$$\frac{\Delta d}{d} = \frac{\Delta t}{t_H}$$

A Universe right now has expansion timescale $t_H = 13.8$ Gyr. Assume the expansion rate has always been constant. A certain galaxy is 100 Mpc away. How long has it been since that galaxy was 50 Mpc away?

A 3.45 Gyr

B 6.90 Gyr

C 13.8 Gyr

D 27.6 Gyr

E 55.2 Gyr

The expansion rate of the Universe is currently accelerating– that is, it is getting faster. It has been accelerating for something like the last 7 billion years.

Right now, we have $t_H=13.6$ Gyr. (Remember that Gyr=gigayears=billion years.) 3.6 billion years ago, was the expansion timescale:

A <10.0 Gyr,

B Exactly 10.0 Gyr,

C between 10 Gyr and 13.6 Gyr,

D exactly 13.6 Gyr, or

E >13.6 Gyr?

C. I have no basis for this answer, but C is said to be most often right on multiple choice exams. I have no idea if this is correct, but I'm just going to follow my instincts.

$t_H = 13.8$ Gyr right now. If the expansion rate of the Universe has been constant, what was t_H 3.8 Gyr ago?

A $t_H < 10.0$ Gyr

B $t_H = 10.0$ Gyr

C $10.0 \text{ Gyr} < t_H < 13.8 \text{ Gyr}$

D $t_H = 13.8 \text{ Gyr}$

E $t_H > 13.8 \text{ Gyr}$

Does a *slower expansion rate* mean a *lower t_H* or a *higher t_H* ?

A Lower

B Higher

If the expansion of the Universe is accelerating, what was t_H 3.8 Gyr ago?

A $t_H < 10.0$ Gyr

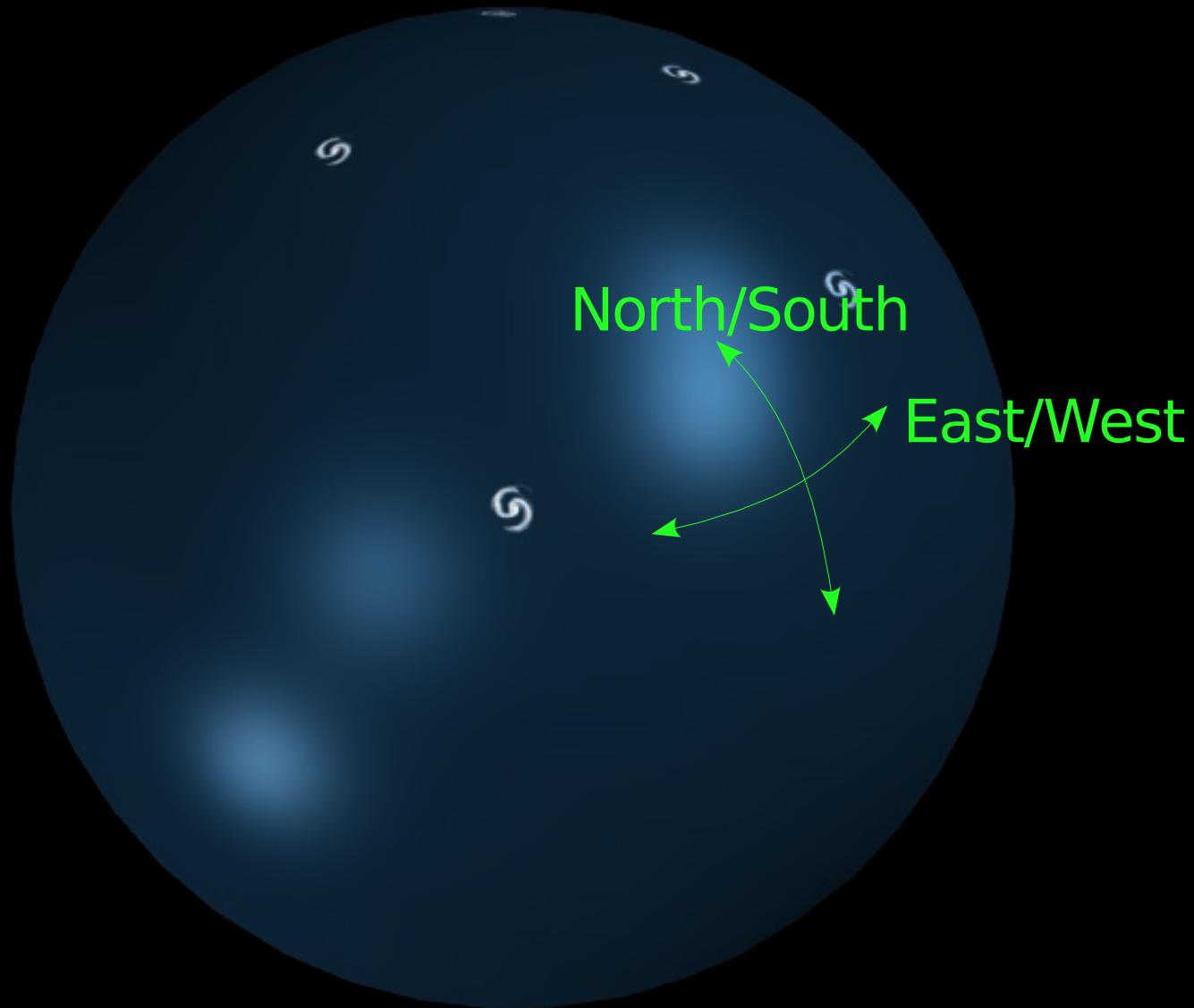
B $t_H = 10.0$ Gyr

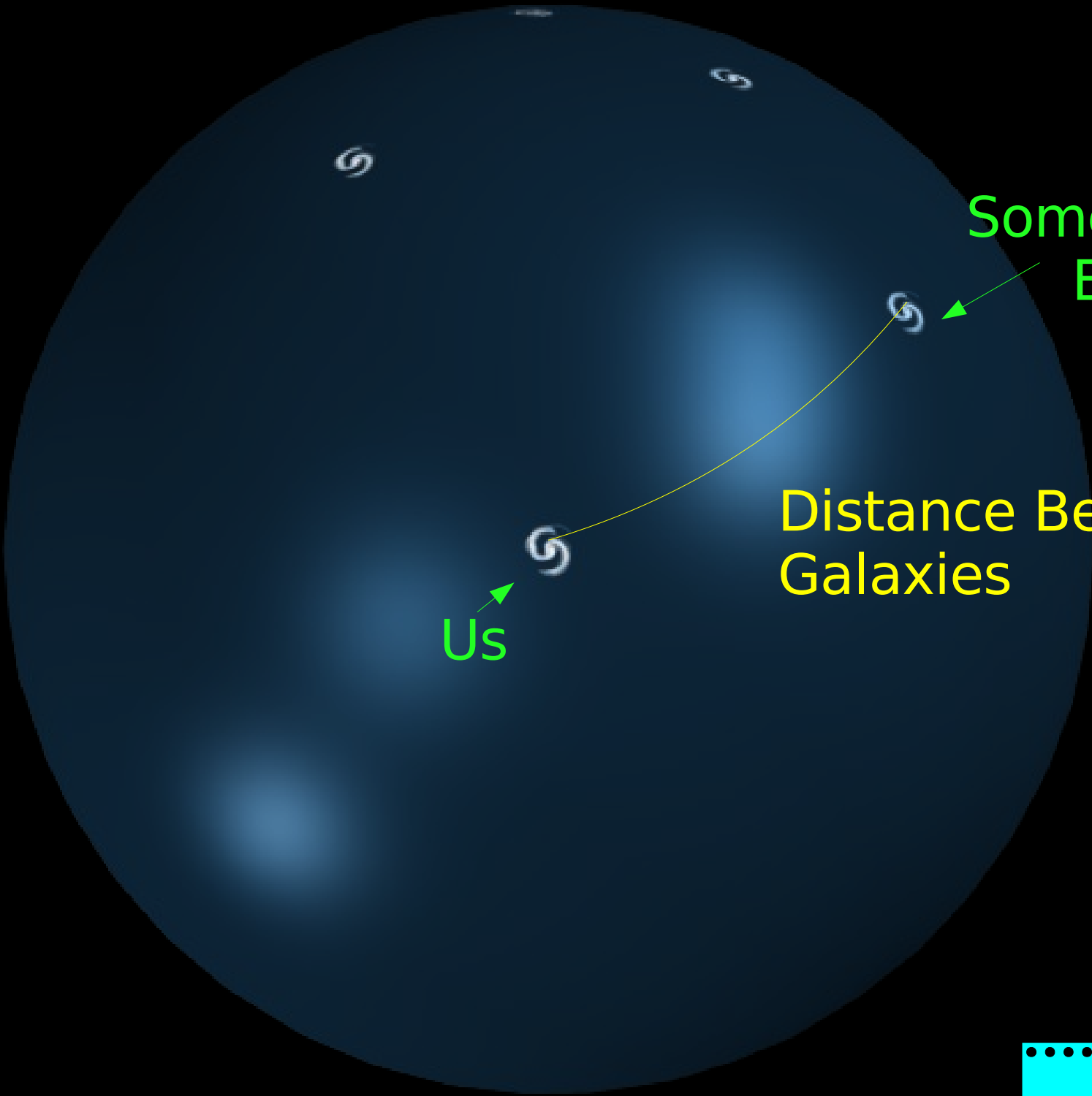
C $10.0 \text{ Gyr} < t_H < 13.8 \text{ Gyr}$

D $t_H = 13.8 \text{ Gyr}$

E $t_H > 13.8 \text{ Gyr}$

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

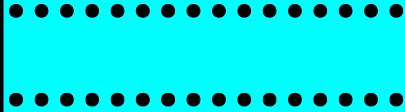




Somewhere Else

Distance Between Galaxies

Us



Redshift

$$z = \frac{\lambda_{\text{obs}} - \lambda_{\text{emit}}}{\lambda_{\text{emit}}} = \frac{\Delta\lambda}{\lambda}$$

This is the *definition* of observed redshift; whatever causes it, it is redshift.

$$1 + z = \frac{\lambda_{\text{obs}}}{\lambda_{\text{emit}}}$$

One possible source of redshift : the Doppler Shift

$$z = \frac{v}{c} \quad \text{for } v \ll c$$

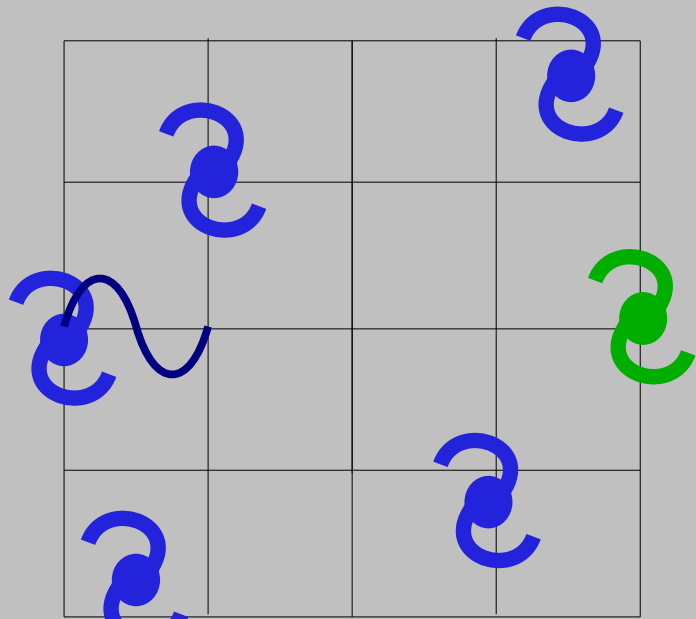
$$1 + z = \sqrt{\frac{1 + \frac{v}{c}}{1 - \frac{v}{c}}} \quad \text{for any } v, \text{ but I'll never make you use that}$$

Cosmological Redshift

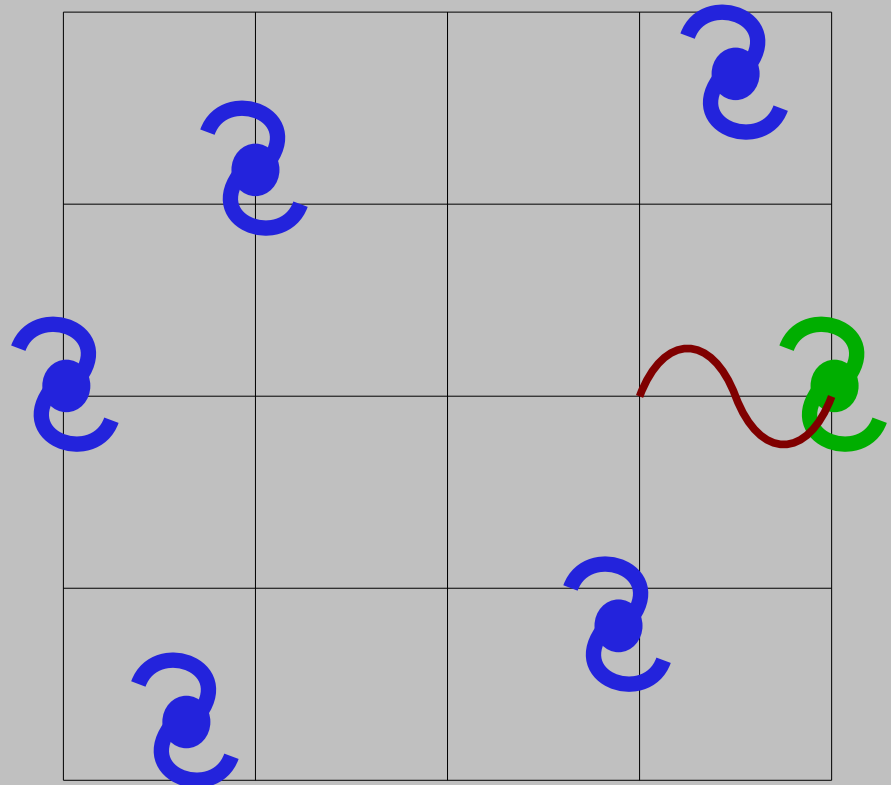
As the Universe expands, the wavelength of light expands *at exactly the same rate*.



Then



Now



R

R_0

Cosmological Redshift

As the Universe expands, the wavelength of light expands *at exactly the same rate*.

$$\frac{\lambda_{\text{obs}}}{\lambda_{\text{emit}}} = 1 + z = \frac{R_0}{R}$$

R = “size of Universe” at emission (average distance between galaxies, or distance to a given galaxy)

R_0 = “size of Universe” now

λ_{emit} = emitted wavelength

λ_{obs} = observed (redshifted) wavelength

$$1+z = \frac{d_0}{d}$$

$$z = \frac{d_0}{d} - 1 = \frac{d_0}{d} - \frac{d}{d}$$

$$z = \frac{d_0 - d}{d} = \frac{\Delta d}{d}$$

The cosmological redshift is a direct measurement of how much the Universe has expanded!!

$$\frac{\Delta d}{d} = \frac{\Delta t}{t_H}$$

$$z = \frac{\Delta t}{t_H}$$

We can also measure Δt – it's lookback time!

The Universe expands by $\Delta d = d_0 - d$ in time $\Delta t = d/c$

Δt = time for light to go distance d (time=distance/speed)

d = initial distance to galaxy – the distance the light goes

d_0 = distance now

$$\frac{\Delta d}{d} = \frac{\Delta t}{t_H} \qquad z = \frac{\Delta t}{t_H}$$

Can Measure
(with a spectrum)

Can Measure
(dimmer std. candle = bigger d)

$$z = \frac{d}{c t_H}$$

Expanding Universe Equation
(only works for $z \ll 1$)

From previous measurements,
today we know this = 13.8 Gyr

Know