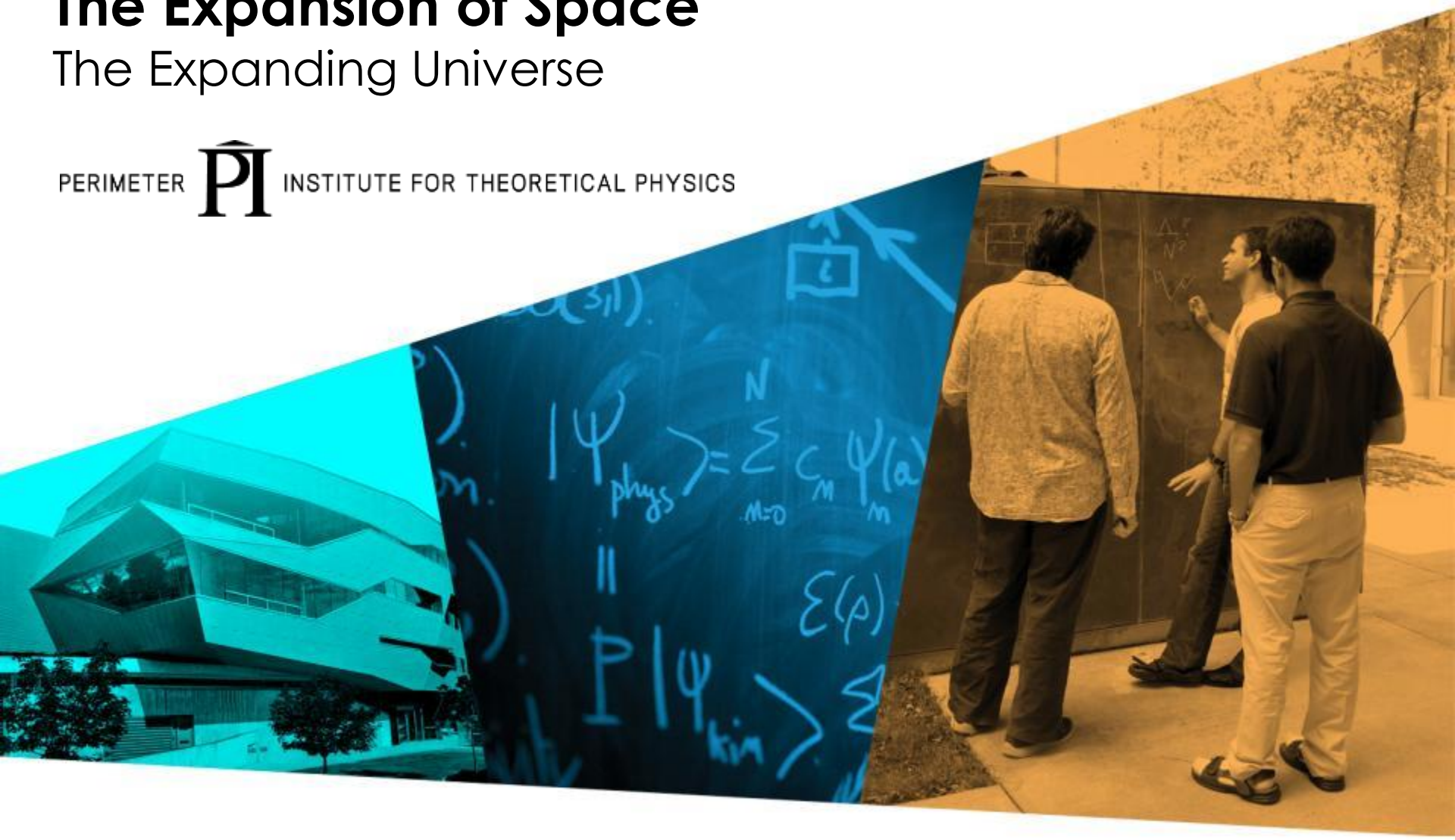
The Expansion of Space

The Expanding Universe

PERIMETER INSTITUTE FOR THEORETICAL PHYSICS



IOP | Institute of Physics In Scotland

SQA Higher Physics

The Expanding Universe

The Doppler effect is observed in sound and light. The Doppler effect causes shifts in wavelengths of sound and light. The light from objects moving away from us is shifted to longer (more red) wavelengths The redshift of a galaxy is the change in wavelength divided by the emitted wavelength. For slowly moving galaxies, redshift is the ratio of the velocity of the galaxy to the velocity of light.	Doppler effect in terms of terrestrial sources, eg passing ambulances. For sound, the apparent change in frequency as a source moves towards or away from a stationary observer should be investigated. Investigating the apparent shift in frequency using a moving sound source and data logger. Applications include measurement of speed (radar), echocardiogram and flow measurement. (Note that the Doppler effect equations used for sound cannot be used with light from fast moving galaxies because relativistic effects need to be taken into account.)	$f = f_s\left(\frac{v}{v \pm v_s}\right)$
Hubble's law shows the relationship between the recession velocity of a galaxy and its distance from us. Hubble's law allows us to estimate the age of the Universe.	Measuring distances to distant objects. Parallax measurements and data analysis of apparent brightness of standard candles. The Unit 'Particles and Waves' includes an investigation of the inverse square law for light. Centres may wish to include this activity in this topic. In practice, the units used by astronomers include lightyears and parsecs rather than SI units. Data analysis of measurements of galactic velocity and distance.	$v = H_o d$

Black Box

Building and revising scientific models

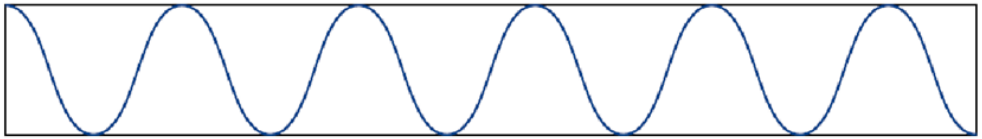
The Expansion of Space

- In the 1920s, Edwin Hubble observed that the light from distant galaxies was redshifted. He believed that it was due to galaxies travelling through space with increasing speeds the farther they were from Earth. However, astronomers now know that this model only works for nearby galaxies. For farther galaxies, a new model is needed.
- As the universe expands, the space between galaxies also expands, moving them farther apart. This gives the impression that galaxies are moving through space away from Earth at speeds that are proportional to their distance from us. This impression is created by the fact that space is expanding so the galaxies get farther apart without actually moving through space.

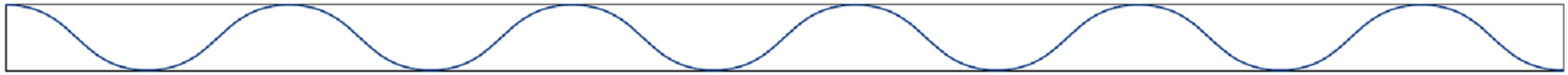
The Expansion of Space

- When radiation, such as light, travels through space, it also stretches along with space itself. When the radiation becomes stretched, its wavelength increases. This is what cosmologists call cosmological redshift. The redder a galaxy appears, the farther away it is, and the faster it is moving relative to us.

Unstretched wave on and elastic bandage:

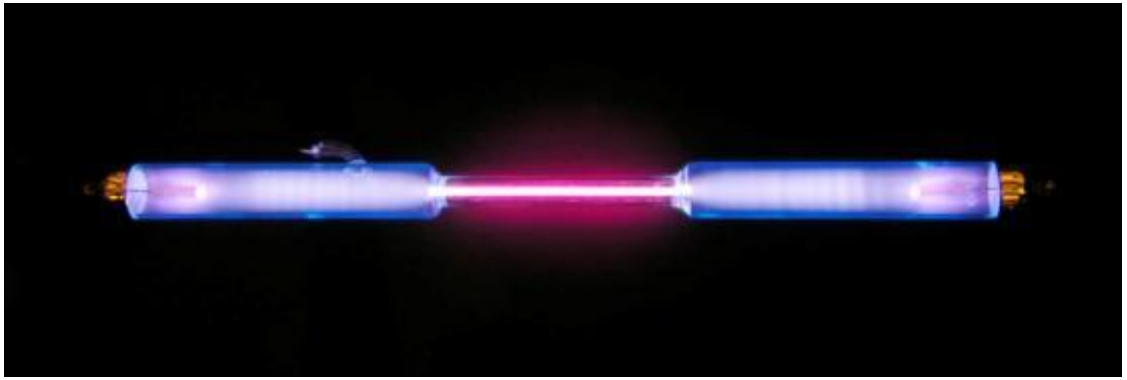


Stretched wave on an elastic bandage:



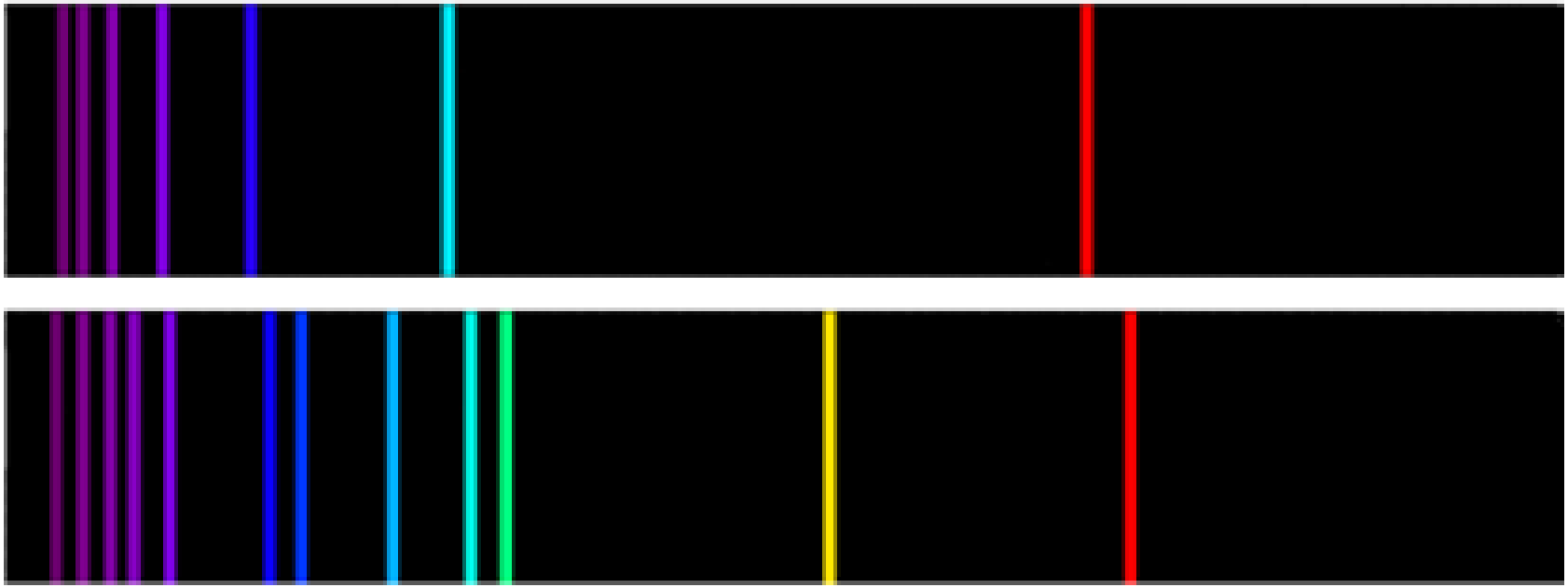
Spectra In the Lab

When elements get excited they release light …



Spectra In the Lab

Every element has a unique spectral signature …



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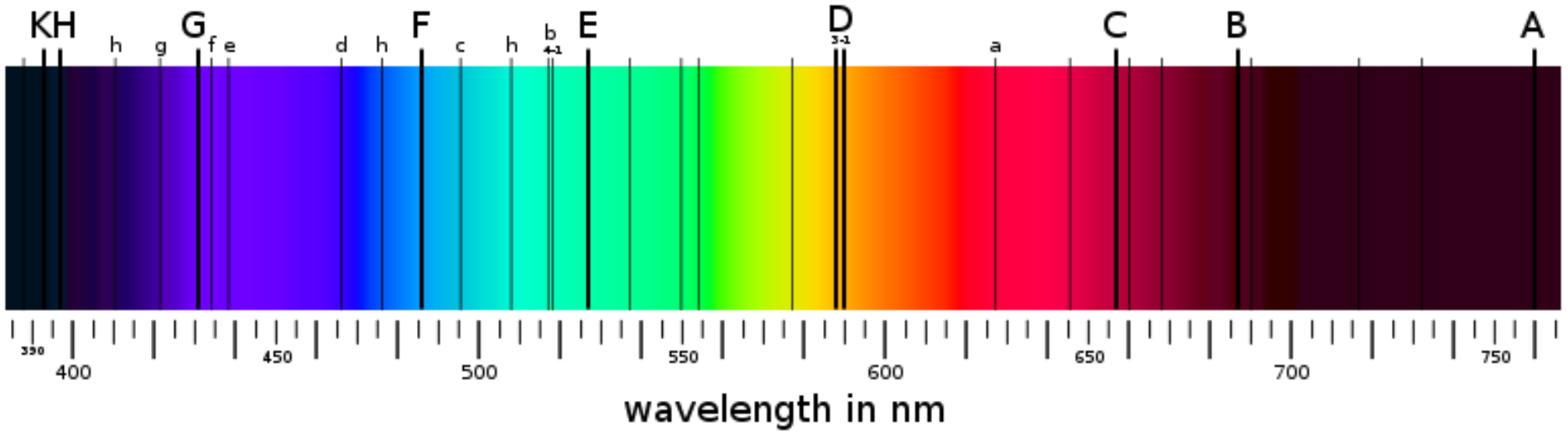
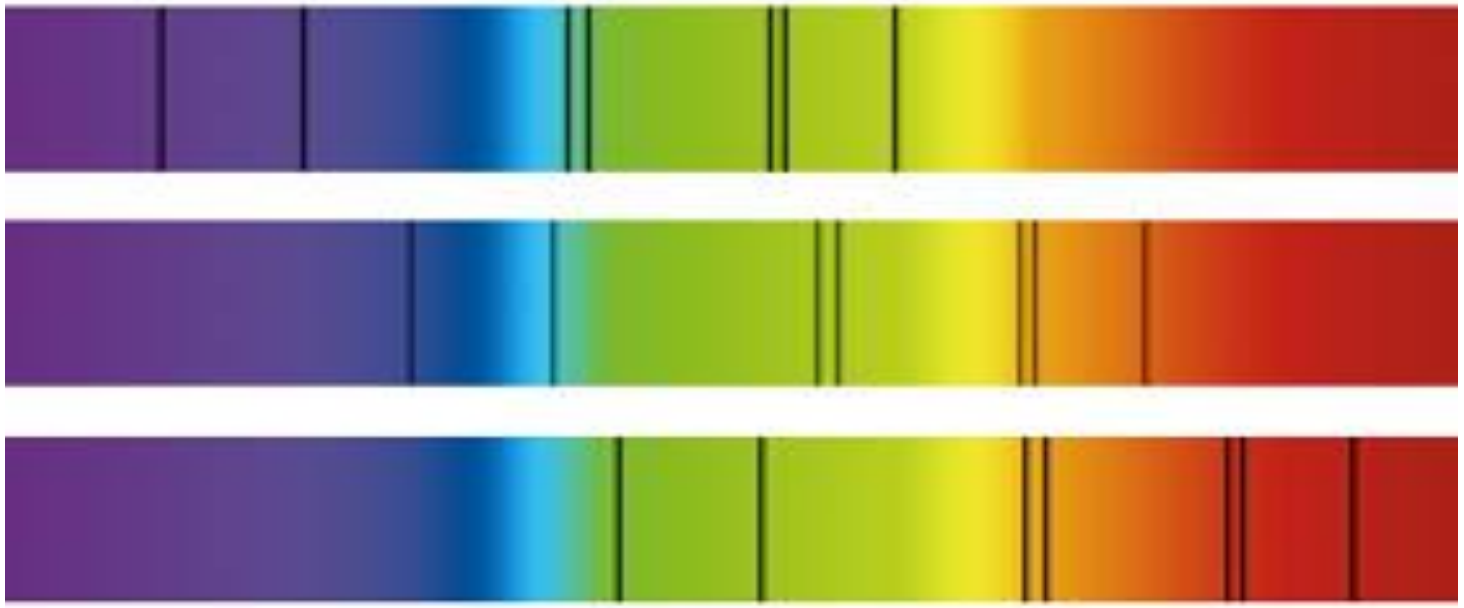
Analyzing Stars

If we look at the light from the sun, we observe the following absorption spectrum:



Hubble–Lemaître Law

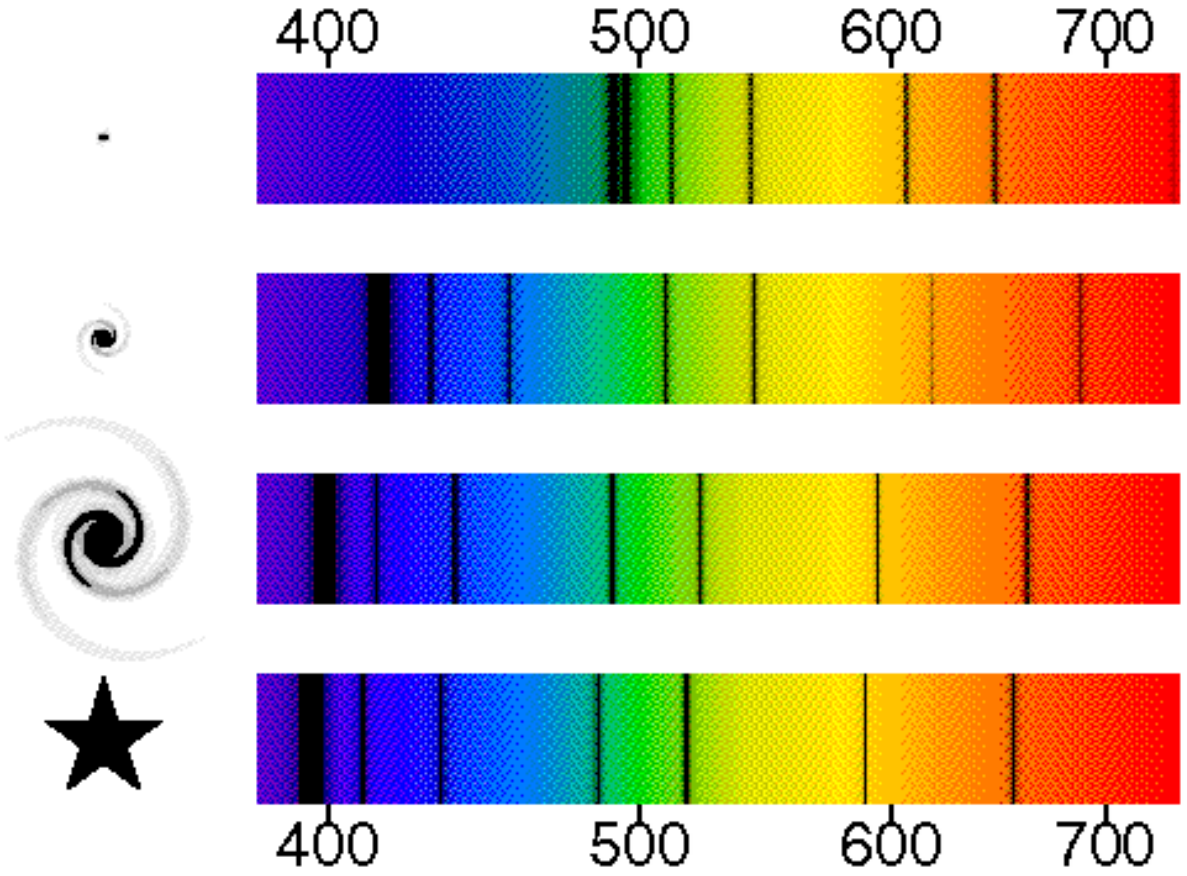
If we look at similar stars at different distances, we notice something strange:



… why have the lines moved?

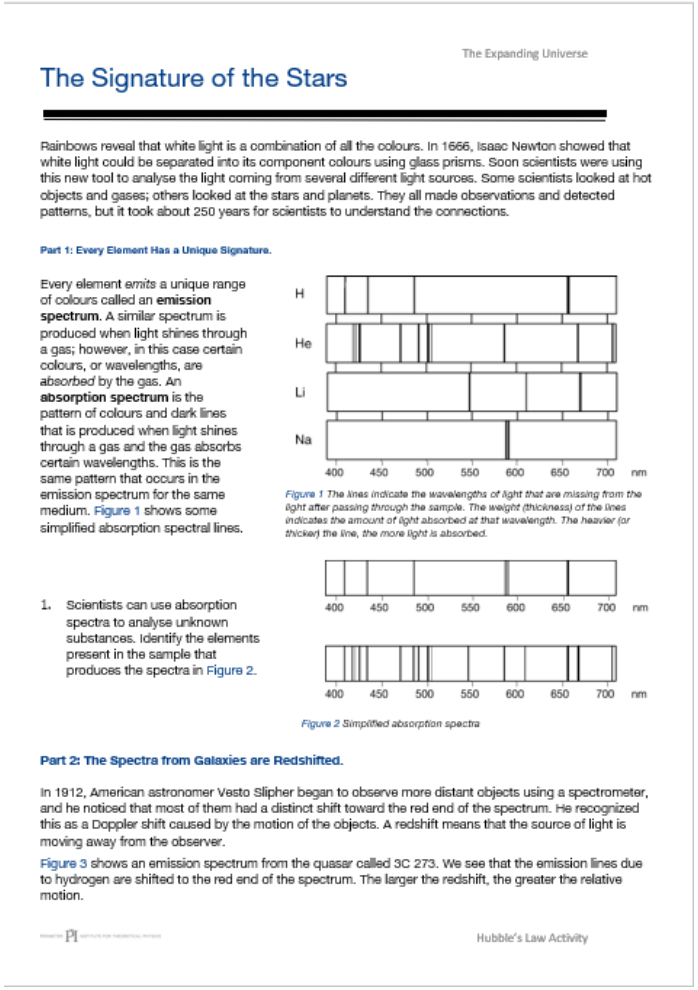
Hubble–Lemaître Law

As we look further away, the lines shift further toward the red end of the spectrum



Hubble–Lemaître Law

- An activity to determine the Hubble–Lemaître constant constant and then to use it to determine the age of the universe.
- Students will measure the redshift of a number of galaxies and plot a graph of recession speed against distance.
- The gradient of this graph gives a value for the Hubble–Lemaître constant.



The Expanding Universe

The Signature of the Stars

Rainbows reveal that white light is a combination of all the colours. In 1666, Isaac Newton showed that white light could be separated into its component colours using glass prisms. Soon scientists were using this new tool to analyse the light coming from several different light sources. Some scientists looked at hot objects and gases; others looked at the stars and planets. They all made observations and detected patterns, but it took about 250 years for scientists to understand the connections.

Part 1: Every Element Has a Unique Signature.

Every element *emits* a unique range of colours called an **emission spectrum**. A similar spectrum is produced when light shines through a gas; however, in this case certain colours, or wavelengths, are *absorbed* by the gas. An **absorption spectrum** is the pattern of colours and dark lines that is produced when light shines through a gas and the gas absorbs certain wavelengths. This is the same pattern that occurs in the emission spectrum for the same medium. Figure 1 shows some simplified absorption spectral lines.

Figure 1 The lines indicate the wavelengths of light that are missing from the light after passing through the sample. The weight (thickness) of the lines indicates the amount of light absorbed at that wavelength. The heavier (or thicker) the line, the more light is absorbed.

1. Scientists can use absorption spectra to analyse unknown substances. Identify the elements present in the sample that produces the spectra in Figure 2.

Figure 2 Simplified absorption spectra

Part 2: The Spectra from Galaxies are Redshifted.

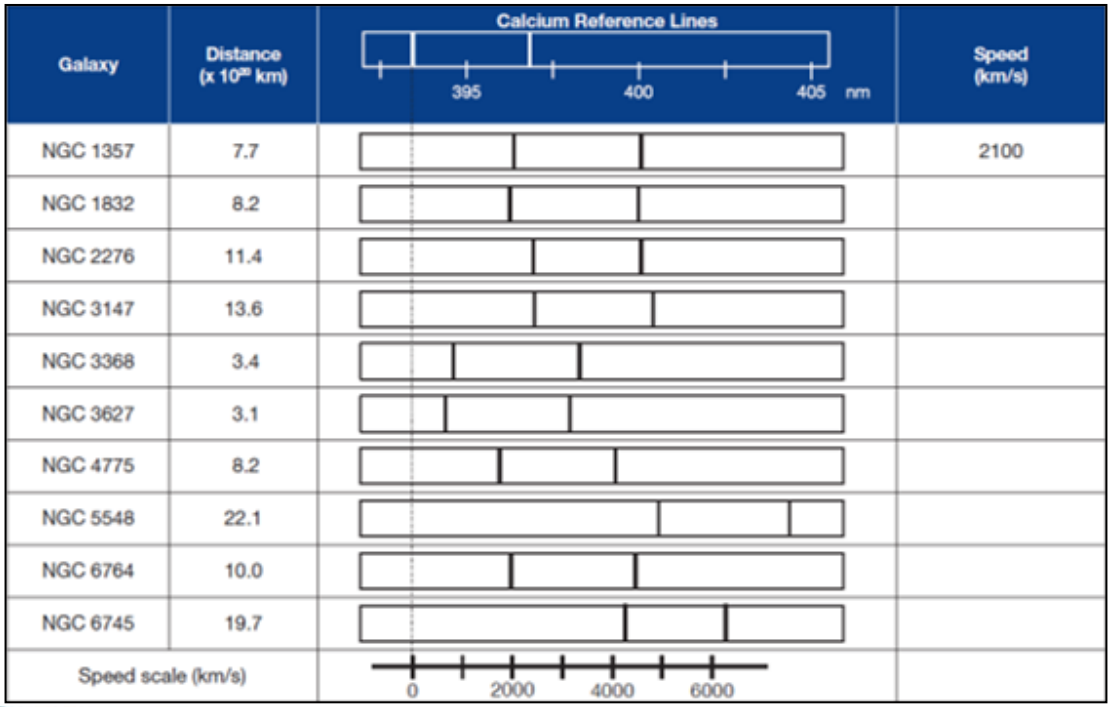
In 1912, American astronomer Vesto Slipher began to observe more distant objects using a spectrometer, and he noticed that most of them had a distinct shift toward the red end of the spectrum. He recognized this as a Doppler shift caused by the motion of the objects. A redshift means that the source of light is moving away from the observer.

Figure 3 shows an emission spectrum from the quasar called 3C 273. We see that the emission lines due to hydrogen are shifted to the red end of the spectrum. The larger the redshift, the greater the relative motion.

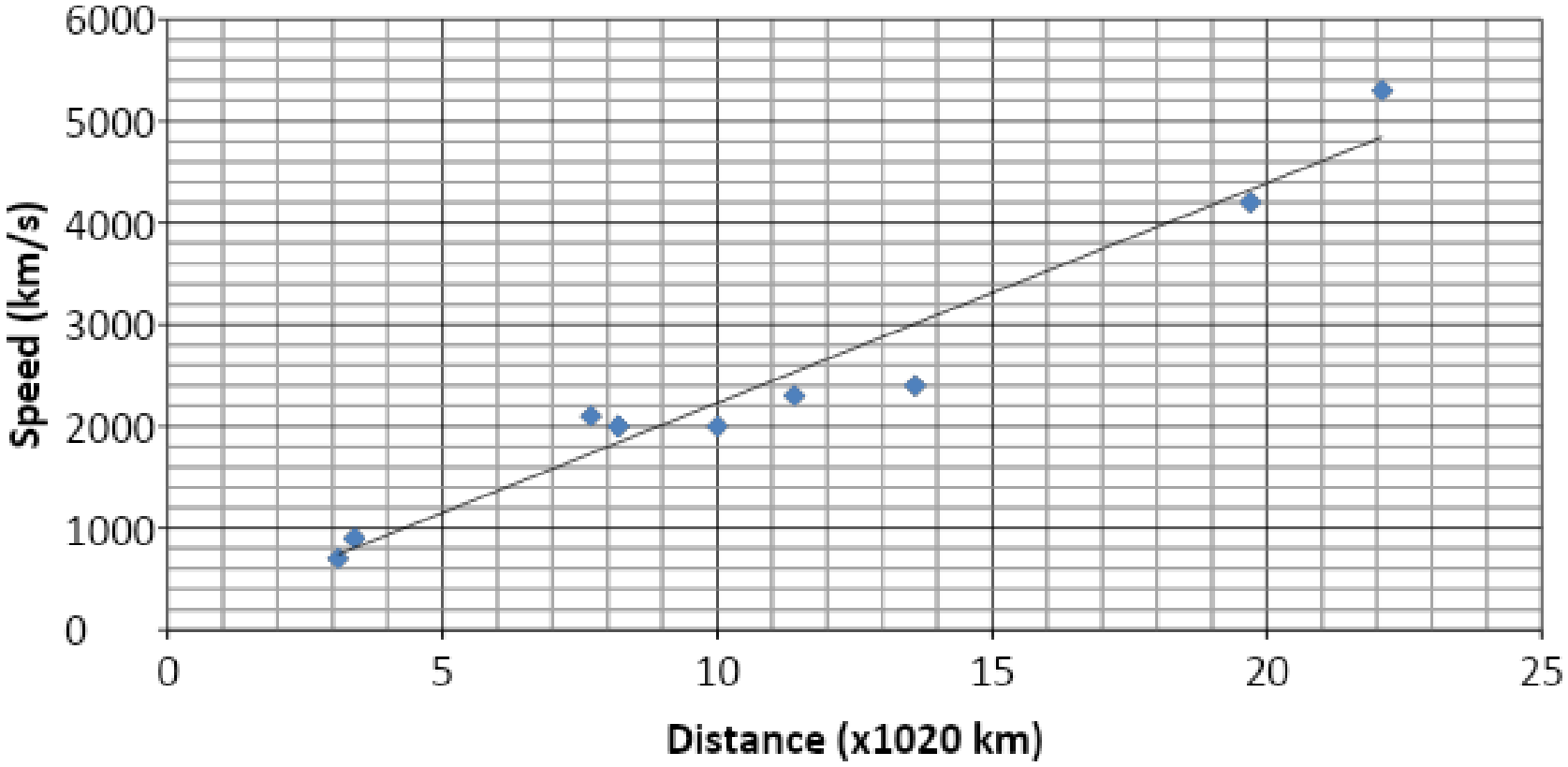
Hubble's Law Activity

Hubble–Lemaître Law

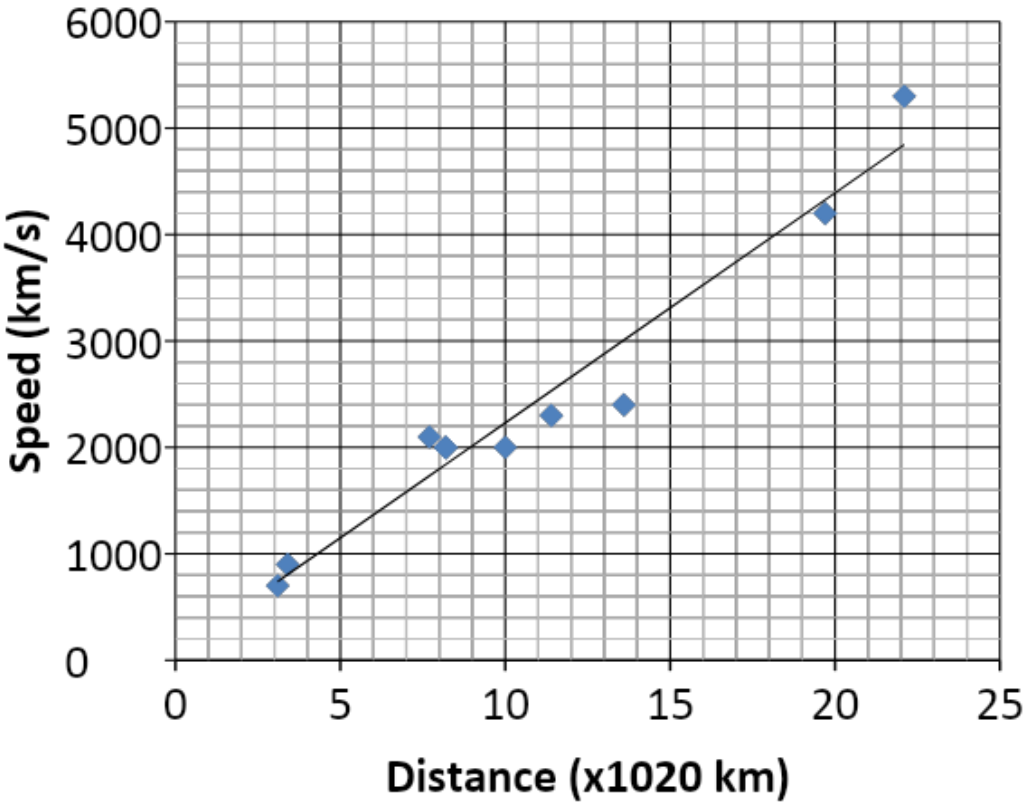
Using a ruler, we can measure how far the spectral lines have become red-shifted and infer information about a galaxy's relative velocity.



Hubble–Lemaître Law



Hubble–Lemaître Law



The further a galaxy is from us, the faster it seems to be travelling.

This can be described with the following equation:

$$v = H_0 d$$

Hubble–Lemaître Law

$$v = H_0 d$$

FARTHER = FASTER

The Hubble–Lemaître constant, H_0, is the rate of expansion.

If we run the expansion backwards, we should be able to calculate the age of the universe …

$$t_{age\ of\ universe} = 1 / H_0$$

Hubble–Lemaître Law

$$H_0 = \frac{\Delta v}{\Delta d}$$

$$= \frac{4400\,\frac{\text{km}}{\text{s}} - 2000\,\frac{\text{km}}{\text{s}}}{20 \text{ x } 10^{20}\ \text{km} - 9 \text{ x } 10^{20}\ \text{km}}$$

$$= 2.2 \text{ x } 10^{-18}\ \text{s}^{-1}$$

Hubble–Lemaître Law

$$t = \frac{1}{H_0} = \frac{1}{2.2\text{x}10^{-18}\ s^{-1}} = 4.58\ \text{x}\ 10^{17}\ s$$

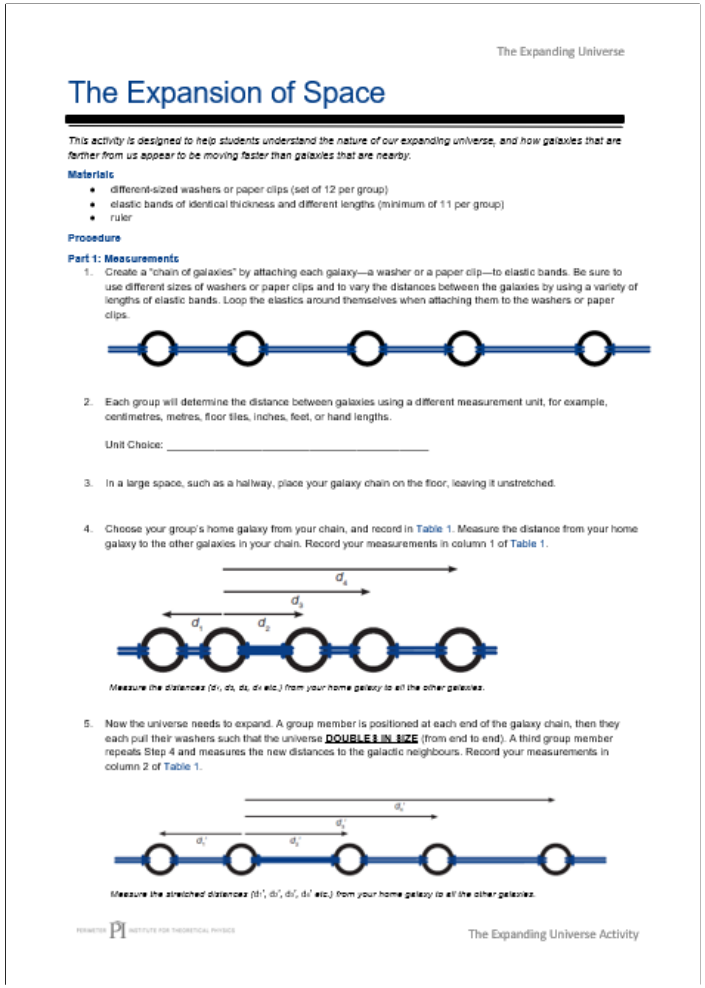
$$t = 4.58\ \text{x}\ 10^{17}\ s \left(\frac{1\ h}{3600\ s}\right)\left(\frac{1\ d}{24\ h}\right)\left(\frac{1\ yr}{365\ d}\right)$$

$$t = 14.5\ \text{x}\ 10^{9}\ yr$$

Not bad … current value is 13.8 x 10^9

The Expansion of Space

- An activity used to demonstrate the expansion of a one dimensional universe using a simple model of washers attached with elastics.
- Students will measure distances between washers in an early and later universe and use guided discovery to confront misconceptions about the expansion of our actual universe.



The Expanding Universe

The Expansion of Space

This activity is designed to help students understand the nature of our expanding universe, and how galaxies that are farther from us appear to be moving faster than galaxies that are nearby.

Materials

- different-sized washers or paper clips (set of 12 per group)
- elastic bands of identical thickness and different lengths (minimum of 11 per group)
- ruler

Procedure

Part 1: Measurements

1. Create a "chain of galaxies" by attaching each galaxy—a washer or a paper clip—to elastic bands. Be sure to use different sizes of washers or paper clips and to vary the distances between the galaxies by using a variety of lengths of elastic bands. Loop the elastics around themselves when attaching them to the washers or paper clips.

2. Each group will determine the distance between galaxies using a different measurement unit, for example, centimetres, metres, floor tiles, inches, feet, or hand lengths.

   Unit Choice: _____

3. In a large space, such as a hallway, place your galaxy chain on the floor, leaving it unstretched.

4. Choose your group's home galaxy from your chain, and record in Table 1. Measure the distance from your home galaxy to the other galaxies in your chain. Record your measurements in column 1 of Table 1.

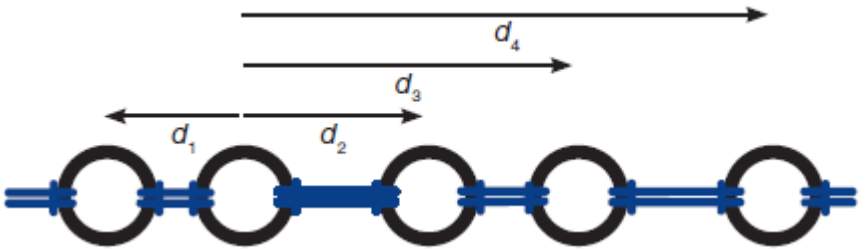
Measure the distances (d_1, d_2, d_3, d_4 etc.) from your home galaxy to all the other galaxies.

5. Now the universe needs to expand. A group member is positioned at each end of the galaxy chain, then they each pull their washers such that the universe **DOUBLES IN SIZE** (from end to end). A third group member repeats Step 4 and measures the new distances to the galactic neighbours. Record your measurements in column 2 of Table 1.

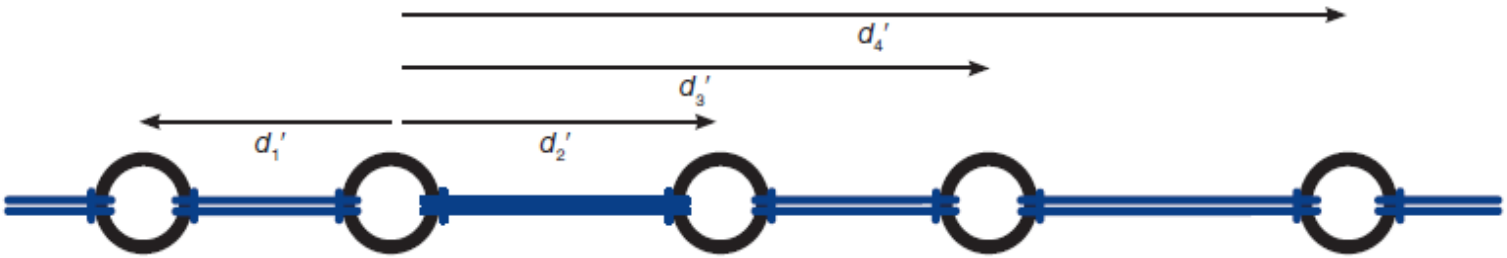
Measure the stretched distances (d_1', d_2', d_3', d_4' etc.) from your home galaxy to all the other galaxies.

The Expansion of Space

- Early Universe:



- Later Universe:

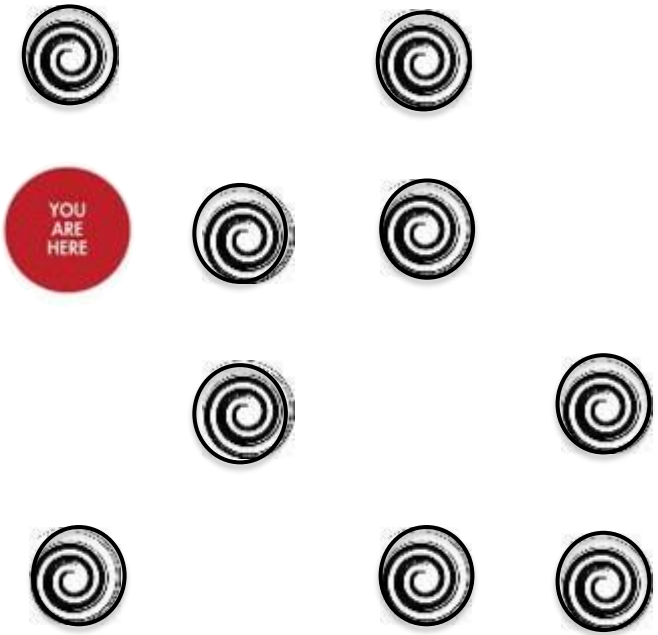


The Expansion of Space

After completing the activity, put yourself in the shoes of the students and answer the inquiry questions listed on the handout.

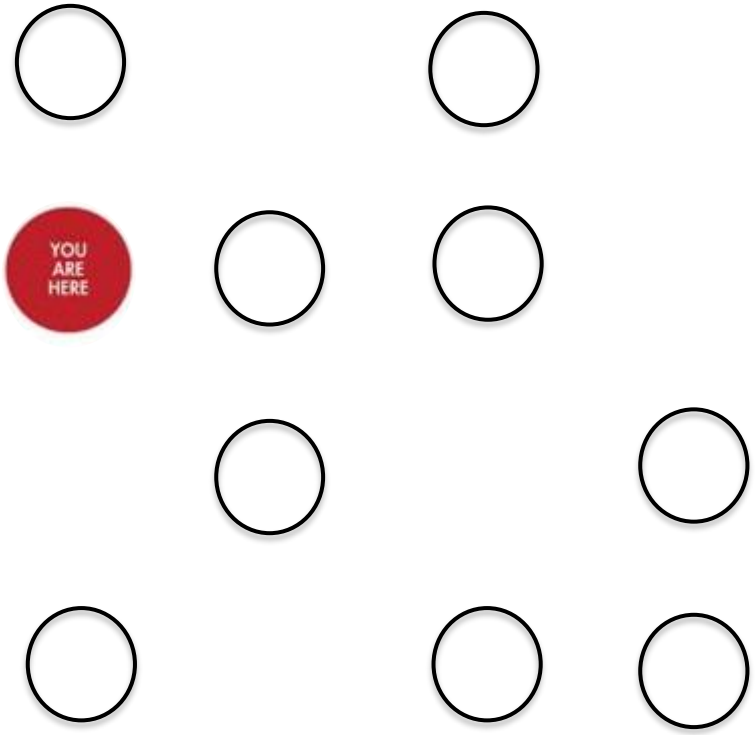
1. Compare your gradient with that of your classmates. What do you notice? What effect does your choice of home galaxy have on the gradient?
2. Describe how the positions of the distant galaxies changed compared to the positions of the nearby galaxies. How does your gradient reflect this?
3. How would the chain look if the gradient value were higher? Lower? How would you describe the universe if the gradient were higher? Lower?
4. Comment on the difference in measurement units used. Is one system better than another?
5. If the universe is expanding, why don't the sizes of the galaxies expand as well?

Predict, Observe, Explain: Where is the Centre?



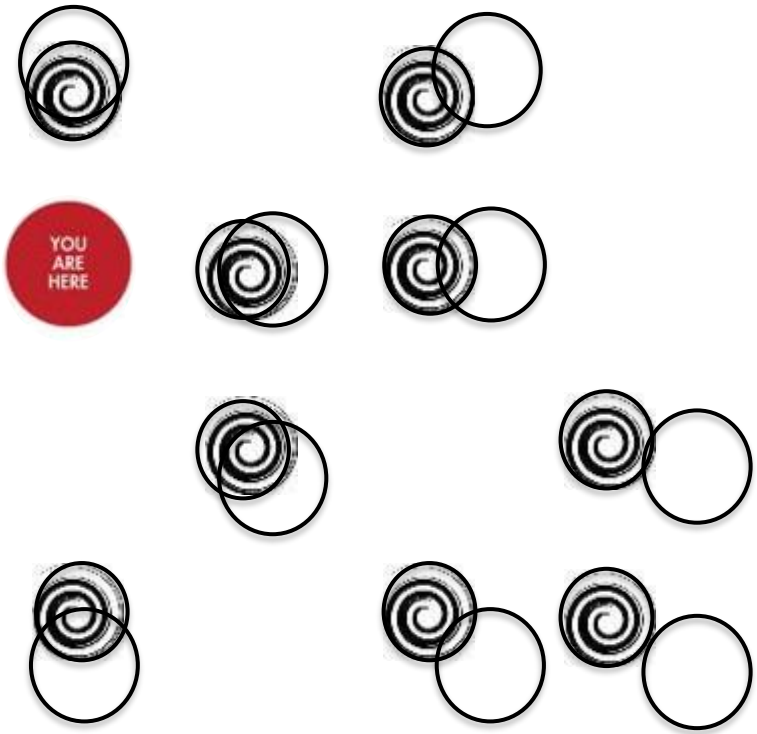
The universe in the past …

Predict, Observe, Explain: Where is the Centre?



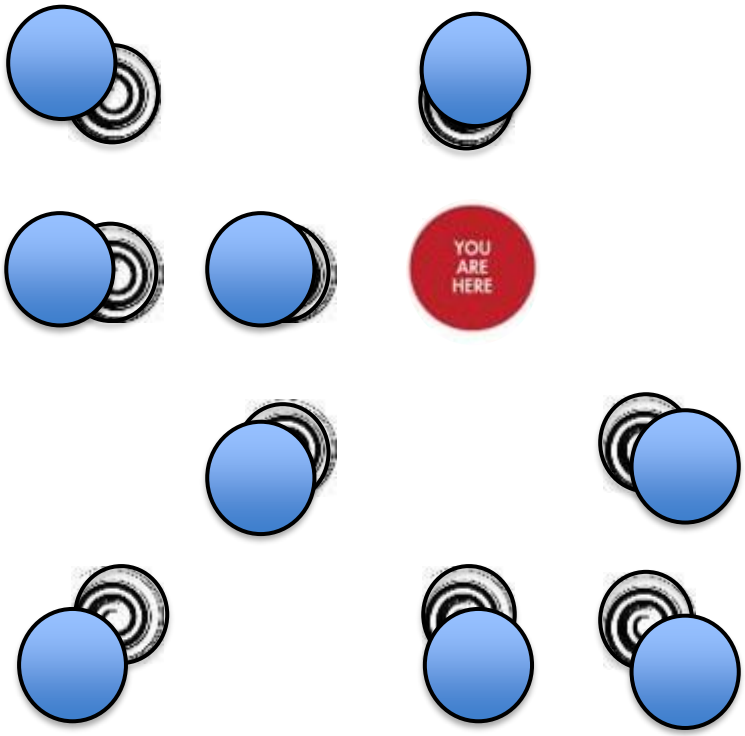
The universe now…

Predict, Observe, Explain: Where is the Centre?



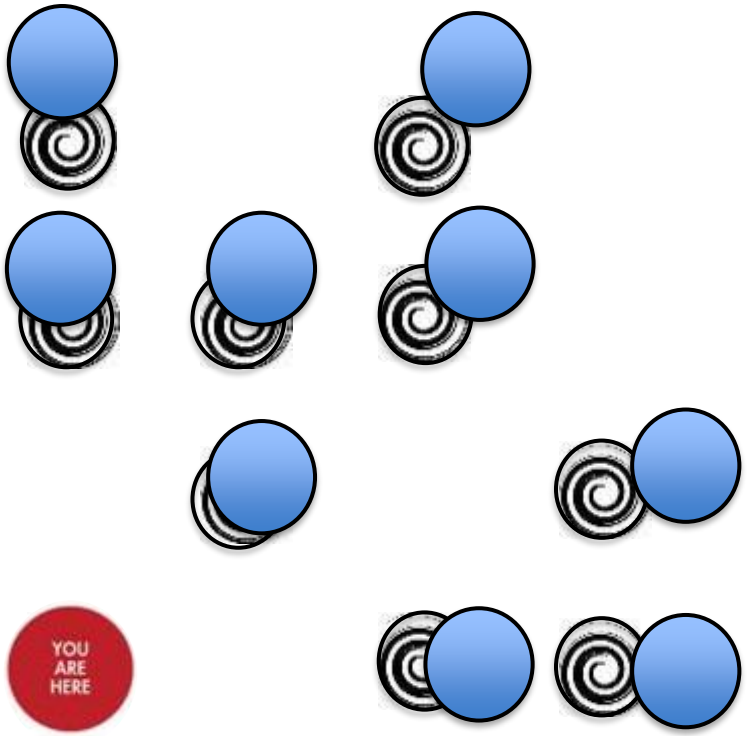
Everything is moving away from us

Predict, Observe, Explain: Where is the Centre?



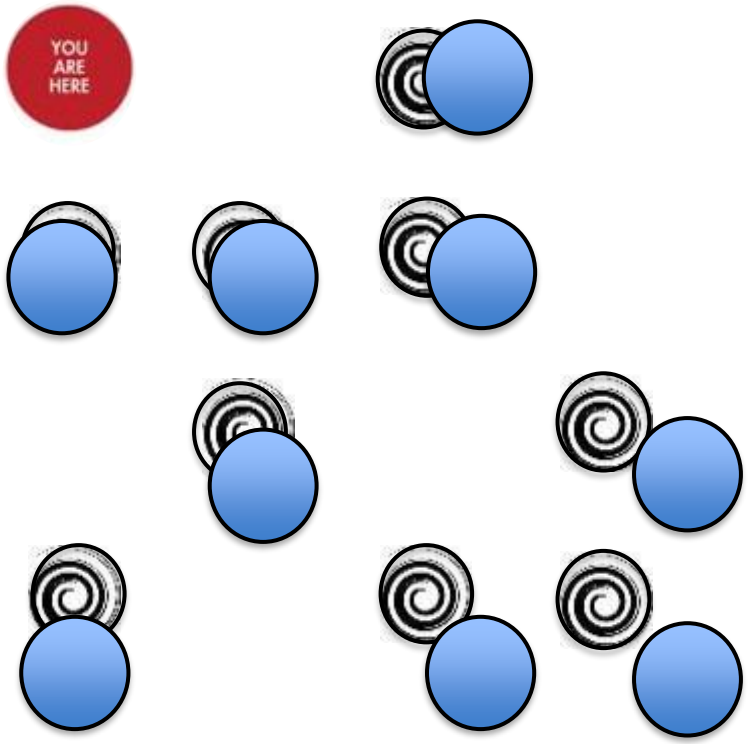
Choose another viewpoint…

Predict, Observe, Explain: Where is the Centre?



Or another viewpoint …

Predict, Observe, Explain: Where is the Centre?

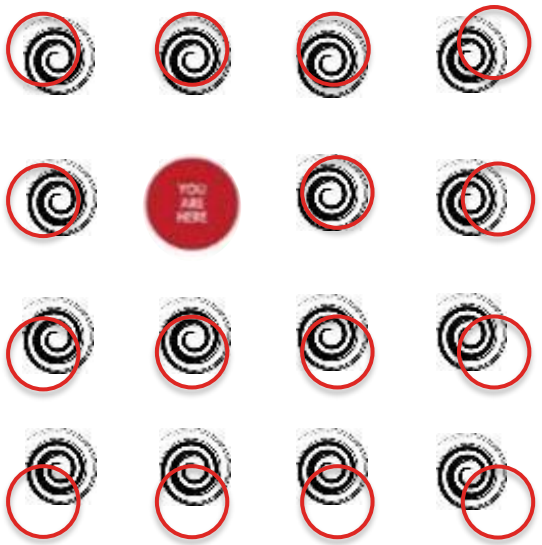


Or another…

Predict, Observe, Explain: Where is the Centre?

It doesn't matter where you are … everything else is moving away from you

There is NO CENTRE!!



Thank You!!

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