CONCEPT 1

The big bang theory is based on two main sets of evidence: redshift and cosmic background radiation.

Activity

Thinking about Waves: Part 1

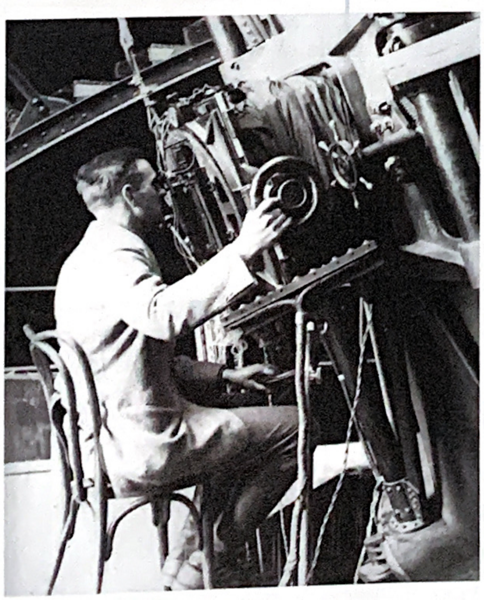
Your teacher may do this as a demo. Fill a tub about half-full of water. Dip the end of a brush handle just below the surface at one end of the tub. Move it back and forth quickly (but without splashing). What do you notice about the waves at the surface of the water? How do waves in front of the handle compare with those behind it? Use a labelled sketch to record your observations.

The big bang theory is a comprehensive theory to explain the origin of the universe—how it began, how it has changed and is changing, how it will end (or will it)? Ideas like this belong to an area of study called *cosmology*. People who inquire about and investigate cosmology are often scientists, but they also may be philosophers, shamans, and even movie-makers. All such people are storytellers. The type of story you will investigate in this Concept, and in much of the rest of this Topic, is the one told by Western science.

The Big Bang Theory and its Evidence

American astronomer Edwin Hubble (1889–1953) began his career as a high school teacher before becoming an astronomer. Using the 2.5 m Mount Wilson Observatory telescope and later the 5 m Mount Palomar telescope (both in California), he photographed and recorded distant galaxies and studied their spectra (**Figure 4.39**).

Figure 4.39 Edwin Hubble using the 2.5 m telescope at Mount Wilson Observatory



The Doppler Effect

Hubble noticed something unusual about the spectra of galaxies. Their spectral lines were slightly displaced from their normal positions. This is known as the Doppler effect. An example of the Doppler effect is the change in pitch of an ambulance siren as it approaches you, passes you, and moves away. As it is moving toward you the siren's sound waves are compressed, resulting in a shorter wavelength and a higher pitch. When it is moving away from you, the siren's sound waves are lengthened, resulting in a longer wavelength and a lower pitch. Light waves behave in a similar way, but while sound waves from a moving object differ in pitch, light waves from a moving object differ in colour.

Redshift and Blueshift

Examine **Figure 4.40**. In spectrum A, the star is not moving. In spectrum B, the spectral lines have shifted toward the blue end of the spectrum. In spectrum C, the spectral lines have shifted toward the red end of the spectrum.

Longer wavelengths are associated with the red end of the spectrum. Since the wavelength of light from an object moving away from an observer is lengthened, toward the red end of the visible spectrum, astronomers say that the spectrum of the object is **redshifted**. Shorter wavelengths are associated with the blue end of the spectrum. Since the wavelength of light from an object moving toward an observer is shortened, toward the blue end of the visible spectrum, astronomers say that the spectrum of the object is **blueshifted**.

Hubble's study of the spectra of the observable distant galaxies revealed that the spectral lines of most of these galaxies are redshifted. Redshifted galaxies are moving away from the Milky Way galaxy. In honour of Hubble's observations, the first large space telescope was named the Hubble Space Telescope.

redshifted for objects moving away from an observer, the effect of lengthening of their wavelengths toward the red end of the visible spectrum

blueshifted for objects moving toward an observer, the effect of shortening of their wavelengths toward the blue end of the visible spectrum

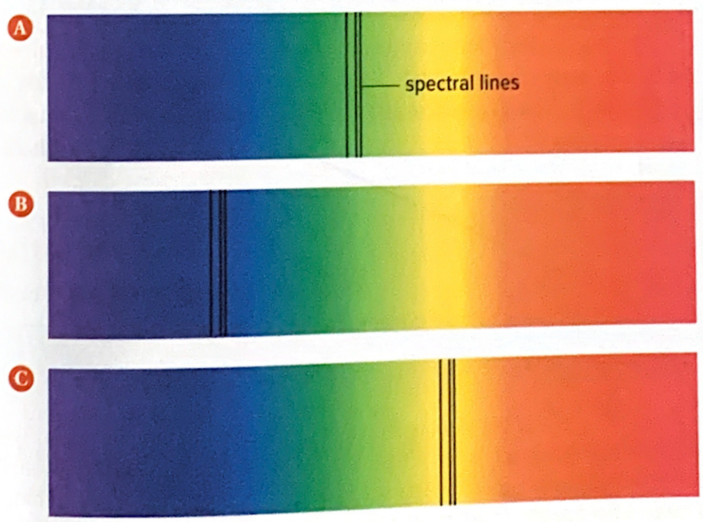


Figure 4.40 The spectral lines indicate the direction of motion of a star. In A, the distance to the star is not changing. In B, the lines have shifted toward the blue end of the spectrum, which indicates that the star is moving toward the observer. In C, the spectral lines have shifted toward the red end of the spectrum, which indicates that the star is moving away from the observer.

Activity

Thinking about Waves: Part 2

Return (in your mind) to the basin and brush activity. Imagine that the brush handle is a star and Earth is located on a spot at the left side of the basin. Sketch how the waves would look to an observer on Earth if the star is moving away. Then sketch how the waves would look if the star is moving toward Earth. Briefly summarize how this information can be used to infer a galaxy's motion in relation to the Milky Way. (Then briefly explain the strengths and limitations of this wave model.)

Conclusions Drawn from Redshift: The Universe Is Expanding

In 1929, Edwin Hubble and another American astronomer, Milton L. Humason (1891–1972), discovered that there is a relationship between a galaxy's redshift and the distance of that galaxy from Earth. They discovered that the speed of a galaxy, which can be determined from the amount or extent of its redshift, is proportional to the distance of the galaxy from Earth.

One explanation for this observation is that all the galaxies (or the space that they take up) began their outward motion at the same time. The galaxies that are moving twice as fast are now twice as far away. (Keep in mind that the galaxies themselves are not moving. The galaxies appear to move and to be getting farther away from us, and from each other, because the space between them is expanding. Galaxies that are farther from us have more space that is growing between them, which causes them to get farther away from us more quickly.

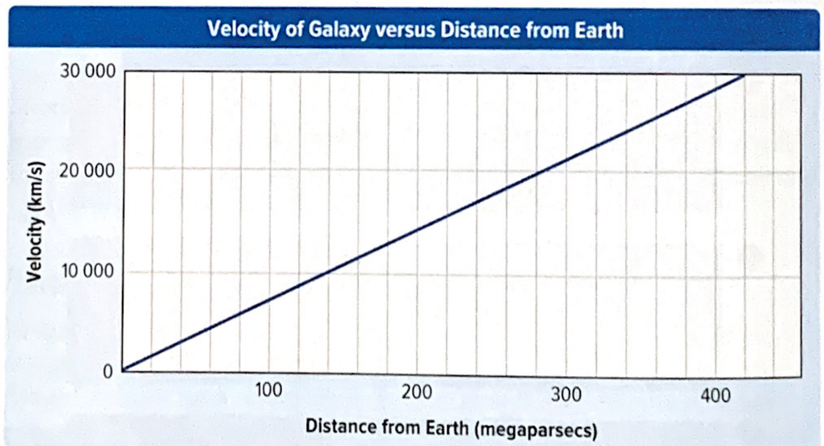


Figure 4.41 The value of the Hubble constant is the slope of the line. Note: The unit for distance in this graph is the megaparsec, which is 3.26×10^6 light-years. Astronomers prefer to use the megaparsec in graphs such as this. **Researching: Who invented the parsec, in what cases is it used in preference to the light-year, and for what reasons?**

Examine the graph shown in **Figure 4.41**. The straight line in the graph means that the speed of a galaxy is proportional to the galaxy's distance from Earth. This relationship is called the Hubble law. A Russian-American physicist, George Gamow (1904–1968), realized the significance of this relationship when he first learned of it: the universe is expanding. The slope of the line in the graph was later called the Hubble constant in honour, yet again, of the work of Edwin Hubble. The Hubble constant is the rate at which the universe is expanding.

The Big Bang Theory and Its Evidence: Cosmic Microwave Background Radiation

The idea of an expanding universe was proposed in 1922 by a Russian physicist, Alexander Friedmann, and further developed in 1927 by a Belgian priest and astrophysicist Georges Lemaître. He suggested that if the universe is expanding, it must have started out very small and dense.

Through the energies that they collect, modern space telescopes (such as the Hubble) can look back in time, almost to the very beginning of the universe. Observations from these technologies show that the universe began its expansion about 13.8 billion years ago. Therefore, the universe is about 13.8 billion years old. Cosmologists theorize that *there was nothing before*—they theorize that time and space in our universe both began 13.8 billion years ago.

No one knows what caused the "beginning." But whatever the cause, many cosmologists believe that our universe began in an event called the big bang. According to the **big bang theory**, the universe began expanding with unimaginable violence from a hot and incredibly dense state to its present state. British astronomer Sir Fred Hoyle (1915–2001) originally coined the term big bang as an insult to Lemaitre's ideas. Hoyle's own steady state theory of the universe stated that the universe did not begin, will not end, and does not change. Therefore, he considered the idea of a big-bang beginning unlikely. There is now convincing evidence of its likelihood.

big bang theory the theory that the universe began about 13.8 billion years ago when something unimaginably small and dense suddenly and rapidly expanded to immense size

Activity

Model an Expanding Universe

1. Fill a non-latex balloon with air until it is the size of a large grapefruit. Then twist the end and hold it closed. Don't tie it shut.
2. Use a pen to draw four galaxies on the balloon in a line, with 1 cm of space between each. Label them A, B, C, and D.

3. Finish inflating the balloon to the size of a volleyball and tie it off.
4. Measure and record the distances between the galaxies.
5. What happened to the distances between galaxies as you blew up the balloon?
6. Imagine you are standing within galaxy A while the balloon is expanding. Which galaxy would appear to move away from you more quickly? more slowly?
7. According to this model, what is moving here? Are the galaxies moving or is space expanding? What is the difference? Discuss your ideas with your classmates.
8. What are the strengths and limitations of this model?

Cosmic Microwave Background (CMB) Radiation

A second piece of evidence to support the big bang theory is the **cosmic microwave background (CMB) radiation**. This is radiation left over from the big bang. Imagine what happened to the radiation in the universe as the universe expanded. Initially, the universe was very hot. It was filled with short-wavelength gamma rays. As the universe expanded, the wavelengths of the gamma rays stretched. As the wavelengths stretched, the radiation changed from gamma rays to visible light. As the universe continued to expand, the wavelengths of the radiation stretched further into cooler parts of the electromagnetic spectrum. Today, the wavelength of CMB radiation that astronomers observe is about 1.07 mm. This is in the microwave part of the spectrum.

cosmic microwave background (CMB) radiation radiation left over from the big bang, which fills the universe

In 1948, Gamow predicted that the CMB radiation had cooled to about −269°C. In 1965, two American scientists, Robert Wilson and Arno Penzias, accidentally discovered this background radiation. They were working for the Bell Telephone Labs in the United States, looking for sources of "noise" (such as radio static) that could interfere with satellite communications. In the process, they kept detecting "static" from all directions in the sky. Other scientists determined that this interference was what we now call the CMB radiation. Its temperature was about −270°C, very close to Gamow's prediction.

COBE and WMAP

The two photos in **Figure 4.42** are all-sky, false-colour maps of the cold microwave background radiation. They are called false-colour maps because the colours are added to indicate slight differences in temperature.

The photos in **Figure 4.42** were taken by two NASA satellites: COBE (COsmic Background Explorer, launched in 1989) and WMAP (Wilkinson Microwave Anisotropy Probe, launched in 2001). Both were designed to measure the CMB radiation. The WMAP image has more detail. In fact, the detailed data gathered by WMAP confirmed the data gathered by COBE.

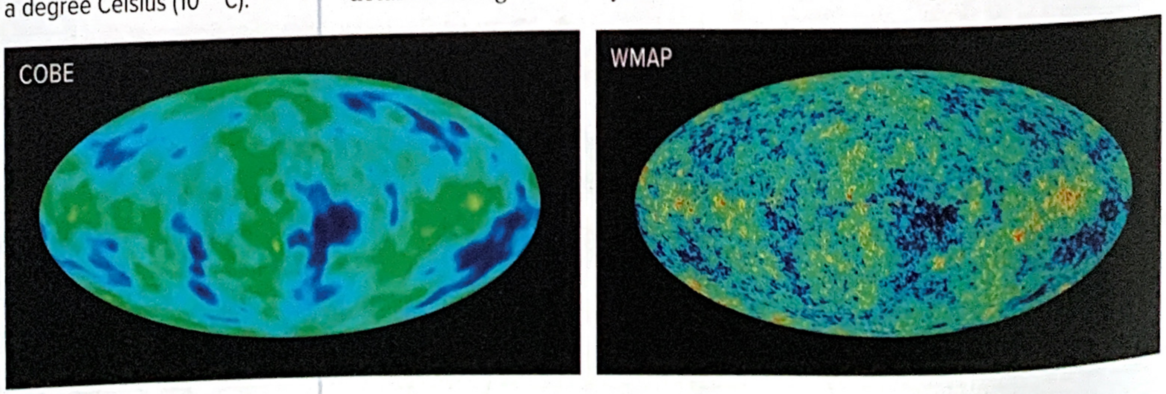


Figure 4.42 Both of these images show the CMB radiation. The colours represent slight variations in temperature. Blue is cooler, and yellow-red is warmer. The temperature variations are only a few millionths of a degree Celsius (10^{-6}°C).

Before you leave this page . . .

1. What is the big bang theory, and what main evidence supports it?