

Chapter 2 The runaway galaxies

In this chapter, we encounter the first plank of evidence for the big bang model - the discovery that the universe contains a large number of galaxies, most of which are rushing away from one another at immense speeds. The universe is not only unimaginably large, it is getting larger all the time!

The great debate

Much more powerful telescopes were developed during the 18th and 19th centuries, based on mirrors rather than lenses.¹ It became clear that our sun is indeed one star in a great galaxy of stars across the sky known as the Milky Way. However, astronomers did not just observe stars and planets through their telescopes; fuzzy clouds of light known as the *distant nebulae* were also observed. These nebulae were carefully studied and catalogued by scientists such as Wilhelm Herschel and William Parsons and an important question arose: were the nebulae located within the Milky Way, or were they distinct galaxies of stars far beyond our own galaxy that were simply too distant to be resolved? This idea, that there might exist ‘island universes’ far beyond our own galaxy, was first articulated by the famous scientist and philosopher Immanuel Kant.²

By the late 19th century, some of the nebulae had been identified as glowing clouds of gas within the Milky Way, while others had been resolved into small clusters of stars associated with it. But one type of nebulae, known to exhibit a spiral structure, proved more difficult to pin down (see figure 1). With the advent of photography, astronomers were able to study the spiral nebulae in a more rigorous manner than before. However, photography does not solve the classic dilemma of the astronomer: how does one distinguish between faint sources of light that are

¹ Telescopes that use a large lens suffer from the problem of chromatic aberration. Newton demonstrated that this problem could be overcome by using a mirror instead of a lens.

² A good overview of early ideas on the ‘island universe’ theory can be found in (Harrison 2001).

relatively close and highly luminous sources that are extremely far away?



Figure 1: A sketch of the spiral nebula M51 observed by William Parsons, the third Earl of Ross, using the 72-inch reflecting telescope at Birr in Ireland 1845.

A great leap forward was made in 1912 by the astronomer Henrietta Leavitt at the Harvard College observatory, when she discovered an important type of star known as a *Cepheid variable*. Cepheid stars have the unusual property that they vary in brightness in a regular, periodic manner. Leavitt discovered that the *frequency* of this variation is related to the intrinsic brightness (or luminosity) of the star. Hence, monitoring the variation in the brightness of a Cepheid gives an estimate of its intrinsic luminosity; and comparing this ‘real’ luminosity with that measured by telescope then gives an estimate of its distance from the observer. In short, Leavitt had discovered a ‘standard candle’ that could be used to calibrate astronomical distances.

Harlow Shapley, an astronomer at Mount Wilson observatory in California, adopted Leavitt’s technique to obtain an estimate of the size of the Milky Way galaxy. By 1918, he had detected several Cepheid stars within structures known as ‘globular clusters’; assuming that the clusters lay within the Milky Way, he was able to estimate of the size of the galaxy. His result was astounding – the Milky Way was at least three hundred thousand light-years³ in diameter.

³ A light-year is the distance light can travel in vacuum in one year - 186,000 km.

This result led Shapley to doubt the island universes theory. After all, the spiral nebulae were only barely visible through the most powerful telescopes - if they really comprised entire galaxies comparable in size to the Milky Way, this implied they must lie at unbelievable distance. Surely the universe could not be that large?

On the other hand, an intriguing piece of evidence emerged from the work of an astronomer at the Lowell Observatory in Arizona, who was using a new technique that measured the *motion* of stars. This technique involved the use of a spectrograph, an instrument that analyzes the spectrum of light emitted by a hot body. (Every star emits light at certain characteristic frequencies; the full 'spectrum' of frequencies is determined by the chemical elements contained in the star). In 1914, the Lowell astronomer V.M. Slipher reported that the spectra of several spiral nebulae were significantly *red-shifted*. The phenomenon of redshift arises from the well-known Doppler effect in physics: the light emitted by a body moving away from an observer is measured by the observer as shifted in frequency towards the lower (or red) end of the spectrum, while it is measured as shifted towards the higher (or blue) end if the body is moving towards him (see figure 2).⁴ By 1914, Slipher had measured red-shifts for thirteen different nebulae and concluded that they were moving away at speeds of up to a thousand kilometers per second. These huge speeds were a great surprise and seemed to imply that the nebulae could not be part of the Milky Way; they were simply receding too fast to be gravitationally bound by our galaxy.

⁴ The same effect can be observed for sound; as an ambulance travels away from an observer, the siren decreases in frequency as well as loudness.

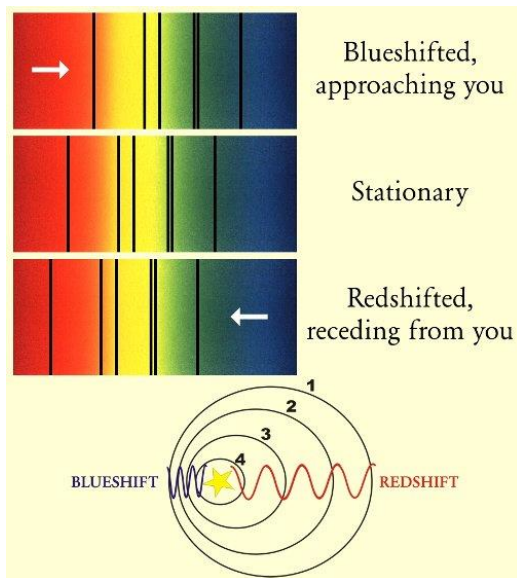


Figure 2: Blue-shift and red-shift of the spectrum of a luminous source due to its motion

Finally, Herber Curtis, an astronomer at the Lick observatory in California, reported a significant number of *novae* in photographs of the spiral nebulae in 1917 (a nova is a star that suddenly flares up in a huge outburst of energy). Such events are rare and seemed to hint that the nebulae might indeed contain a huge number of stars. In addition, most of the novae were observed as extremely faint, suggesting that they might lie at great distance.

The evidence was perplexing and the debate concerning the size of the Milky Way and the nature of the spiral nebulae raged back and forth for some years. In 1920, Shapley and Curtis, (the latter a firm proponent of the 'island universes' theory) were invited to present their opposing viewpoints at a famous meeting of the National Academy of Sciences in Washington.⁵ The outcome was inconclusive, but a clear resolution of the debate was soon to be provided by yet another telescope....

⁵ See (Smith 1982).

The resolution of the great debate

In 1918, a reflecting telescope with a mirror 100 inches in diameter became operational at Mount Wilson Observatory in California. It was the most powerful telescope in the world and remained so for decades. One of the first people to use the telescope was the astronomer Edwin Hubble, who joined the Mount Wilson staff in September 1919. Hubble, a brilliant and multi-talented academic, had trained as a research astronomer at the Yerkes Observatory of the University of Chicago, using their 40-inch refracting telescope to take photographs of the faint nebulae. By 1919, he had already come to suspect that the spiral nebulae lay far beyond the Milky Way galaxy.

At Mount Wilson, Hubble embarked on a systematic study of the distant nebulae with the new telescope. His first triumph was a classification scheme of all known nebulae, completed by 1923. That year, he started a series of detailed observations of the spiral nebula M31. Almost immediately, he scored an important advance with the clear identification of a Cepheid variable in the spiral. Using the Cepheid as a standard candle (see above), Hubble was able to estimate that the cloud lay at a distance of approximately *one million* light-years away – far larger than Shapley's estimate of the diameter of the Milky Way and strong evidence that M31 was a separate galaxy located outside the Milky Way. By 1925, he had identified Cepheid variables in thirteen nebulae and measured the distances to each in millions of light-years. Clearly, the spiral nebulae were island galaxies far beyond the Milky Way - the Great Debate was over.

Hubble's law

Hubble's measurements of astronomical distance provided a clear resolution to a longstanding

debate in astronomy. Better still, as so often happens in science, the project led to a separate discovery of immense importance that almost nobody anticipated.

Aware of Slipher's measurements of the recession speeds of the spiral nebulae (now known to be distinct galaxies), Hubble set about investigating whether there is a relationship between the *distance* to a particular galaxy and its *motion*. He was extremely interested in this project and enlisted the support of Milton Humason, a gifted technician and observer at Mount Wilson, to adapt the Hooker telescope for spectroscopic measurement so that Slipher's redshift technique could be extended to more distant galaxies. Combining his own measurements of galaxy distances with Slipher's redshift data, Hubble made the tentative discovery that there is indeed a very simple relationship between the distance to a galaxy and its recession speed: *the more distant a galaxy, the faster it is moving away!* This linear relation⁶ can be seen in the graph in figure 3, reproduced from the original paper (Hubble, 1929). Note that the relation is independent of the position of the observer; the galaxies are rushing away from each other, not just from an earthbound observer.

⁶ A linear relation between any two variables x and y is of the form $y = mx + c$, where c is a constant and m is the constant of proportionality, measured as the slope of a graph of y against x . Hubble's law is written as $v = Hd$, where v is the velocity of a galaxy, d its distance from the observer and H is the slope of the Hubble graph.

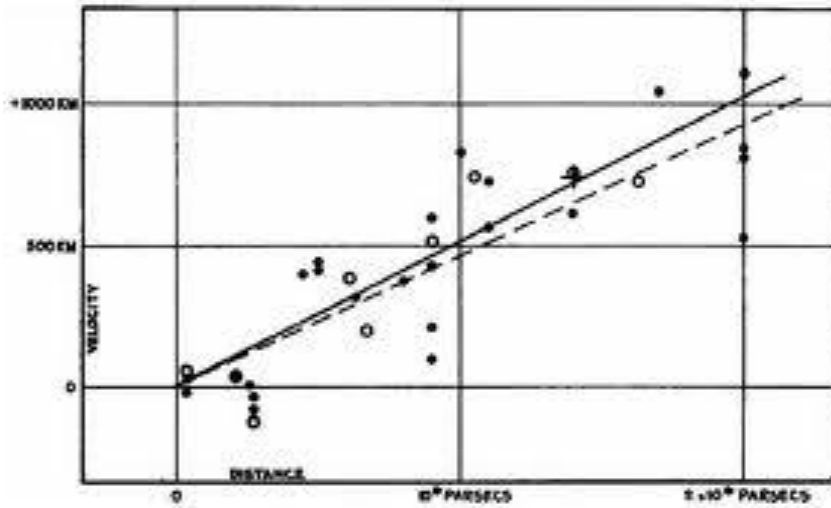


Figure 3: Graph of velocity versus distance for the galaxies (Hubble, 1929).

Hubble's graph was a great surprise, and by 1931, he and Humason had extended the measurements to include redshifts and distances for more than forty distant galaxies. All seemed to obey the simple velocity/distance relation that later became known as *Hubble's law* (figure 4). That said, it should be noted that the discovery was not immediately accepted by the world of science, mainly because the interpretation of redshift as velocity was somewhat uncertain.

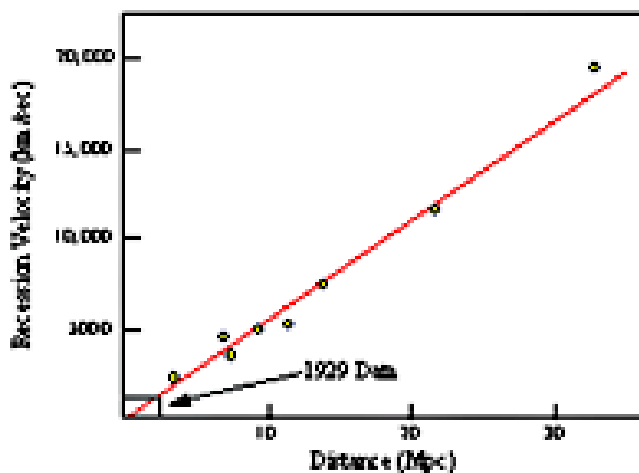


Figure 4: Graph of velocity versus distance for many galaxies (Hubble and Humason, 1931).

In retrospect, Hubble's law marked a huge advance in both astronomy and cosmology. In astronomy, it was now possible to estimate the distances of extremely far flung galaxies by measuring their redshifts (it is much easier to measure the frequency of light from a star than it is to measure its absolute distance).⁷ Of course, such estimates rely critically on the slope of the velocity/distance graph, now known as the *Hubble constant* H . As we shall see, a systematic error in Hubble's measurements of distance led to an erroneous value for the Hubble constant that persisted for many years.

As regards cosmology, our view of our universe was transformed forever. The universe was not only much larger than anyone had imagined, it was getting larger all the time! How could this be? What was pushing the galaxies away from one another? In the classical physics of Newton, gravity is the only force that acts on matter over long ranges; but gravity is an *attractive* force, not a repulsive one (see chapter 3). Hence, classical physics could not explain the runaway galaxies. Note that the expansion is only on cosmic scales; our own galaxy is certainly not expanding and our nearest galaxy is approaching us.⁸ In the next chapter, we shall see that an off-the-shelf explanation was already to hand, courtesy of one of the most radical scientific theories of all....

On the philosophy of science

⁷ Indeed, Hubble's motivation in this project was that if a simple relation could be found between distance and redshift, the measurement of redshift would provide a formidable new method of estimating the distance to far flung galaxies.

⁸ There is a wonderful scene in the Woody Allen film '*Annie Hall*' where the main character is concerned that New York is expanding.

Two great changes in worldview occurred in this part of our story – the discovery that our galaxy is but one among many in an extremely large universe, and the discovery that the distant galaxies are rushing away from one another. Such changes in worldview were labelled *paradigm shifts* by the historian and philosopher of science Thomas Kuhn. In Kuhn's view, such paradigm shifts occur when enough evidence has accumulated to overthrow the established view. However, Kuhn also took the view that the shift from one paradigm to another does not arise as a result of evidence alone, but is determined at least in part by social context.⁹

Many scientists would agree that the *discovery* of the receding galaxies was dependent upon social factors such as the background and training of the pioneering astronomer Edwin Hubble, and his access to the world's largest telescope. However, most would add that the new paradigm was eventually adopted because the results could be explained in terms of theory (see chapter 3) and because they were later supported by diverse measurements – together this forms what is known as the *context of justification*. This view of science is rather more conservative than that of Kuhn and is in marked contrast with more radical sociologists of science, who believe that scientific facts are *constructed* rather than discovered (for example, they would assert that the measurements that followed Hubble's pioneering work were probably influenced by the high regard in which he was held). For their part, practicing scientists point to the high standard of evidence required in order to have results published in a reputable journal and to the fact that research groups spend a great deal of time trying to prove each other wrong!

We shall revisit these opposing views of science throughout the book – for the moment, we simply note that Hubble's law has stood the test of time admirably. That said, we shall also see

⁹ See (Kuhn, 1976).

that his results contained a significant systematic error that was not detected for many years, so perhaps the sociologists are right to some extent.