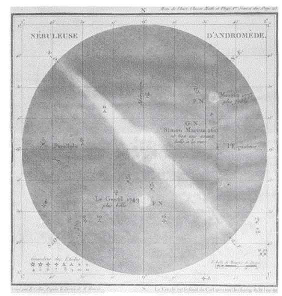
Section Two/Crowe/Expanding Universe
Chronology of Stellar Astronomy and Cosmology, Leading up to the Expanding Universe Theory[1]
(M. J. Crowe)

Questions to Be Answered Include:
What is the size, structure, and age of the universe?
What is the size and structure of the Milky Way?
How and by whom were these questions answered?
What is the expanding universe theory and how and by whom did it come to be formulated?

1755 Immanuel Kant publishes his *General Natural History and Theory of the Heavens* in which he lays out the so-called **island universe theory**, i.e., the theory that the appearance called the Milky Way is due to our being located in a vast disk-shaped structure of stars and that objects called nebulae are other Milky Ways.



Messier's Drawing of Andromeda

1782 Charles Messier publishes a catalogue of **103 nebulae**, the most complete list then available. Astronomers used the term *nebulae* to refer to dim, diffuse, cloud-like objects, nearly all of which can be seen only with telescopes. Some objects so described were Orion, Andromeda, and, in the Southern Hemisphere, the Magellanic Clouds.

1783 William Herschel (1738–1822) completes the construction of his 18.7-inch aperture, 20–foot focal length reflector, which he uses to observe nebulae.

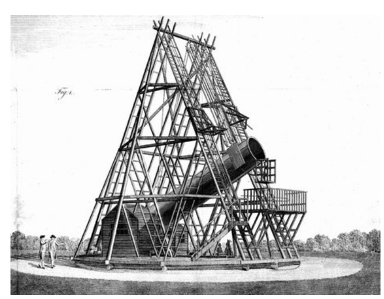

William Herschel

1784 Herschel reports **discovering 466 new nebulae**, noting his success in resolving many of them into individual stars.

1785 Herschel publishes his second major paper on nebulae; also presents theory that the appearance known as the **Milky Way** is due to our being located in an immense, disk-shaped structure of stars.

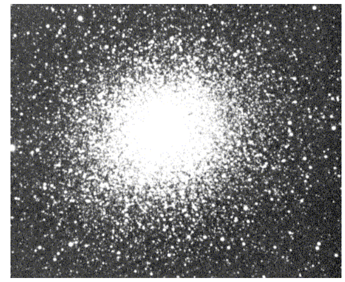
1786 Herschel publishes a catalogue of the 1000 nebulae that he had discovered.

1789 Herschel completes construction of his 48–inch aperture, 40–foot-focal length reflecting telescope (see picture). It would remain the largest telescope ever made until 1845.



[1]For fuller information, references for quotations, etc., see M. J. Crowe, *Modern Theories of the Universe from Herschel to Hubble* (New York, Dover, 1994).

1789 Herschel publishes a catalogue of 1000 additional nebulae; publishes a major paper on **globular clusters,** which are nebulae with spherical symmetry, some of which Herschel could resolve into individual stars. The most famous globular cluster is M13, the globular cluster in Hercules.



1791 Important paper entitled "On Nebulous Stars, Properly So Called," in which Herschel reports on his analysis of an object that is now known as a **planetary nebula**, that name being used because the object has a circular form somewhat similar to that exhibited by planets, but with a bright star in the center. Concludes that the nebulous area around the star must be a "**shining fluid,**" which leads him to question whether all nebulae are composed of clusters of stars. A serious problem faced by astronomers was that there seemed no direct way to determine how far away from us any of the nebulae are.

1792 John Herschel, only child of William Herschel, born.

1802 William Herschel publishes catalogue of 500 additional nebulae.

1811 Herschel publishes paper presenting a new theory of the nebulae and their role in the evolution of the heavens. Suggests that they are stars in the process of formation.

1822 **Death of William Herschel,** having discovered ca. 2500 new nebulae and having pioneered the study of stellar astronomy, the area of astronomy dealing with the region beyond our solar system. His main legacy was to raise in a very effective way the question of what are the nebulae, in particular, are they island universes?

1833–38 John Herschel spends four years in Cape Town at the southern tip of Africa, observing the southern heavens with a large reflecting telescope. Discovers numerous new nebula, maps the Larger Magellanic Clouds, and constructs a diagram showing that the nebulae typically lie off the plane of the Milky Way. John Herschel was the first astronomer to have made a thorough study of the stellar and nebular regions of both the northern and southern celestial hemispheres.

John Herschel

1838 Friedrich Wilhelm Bessel measures the first **stellar parallax.** This provides a measurement of the distance of the star.

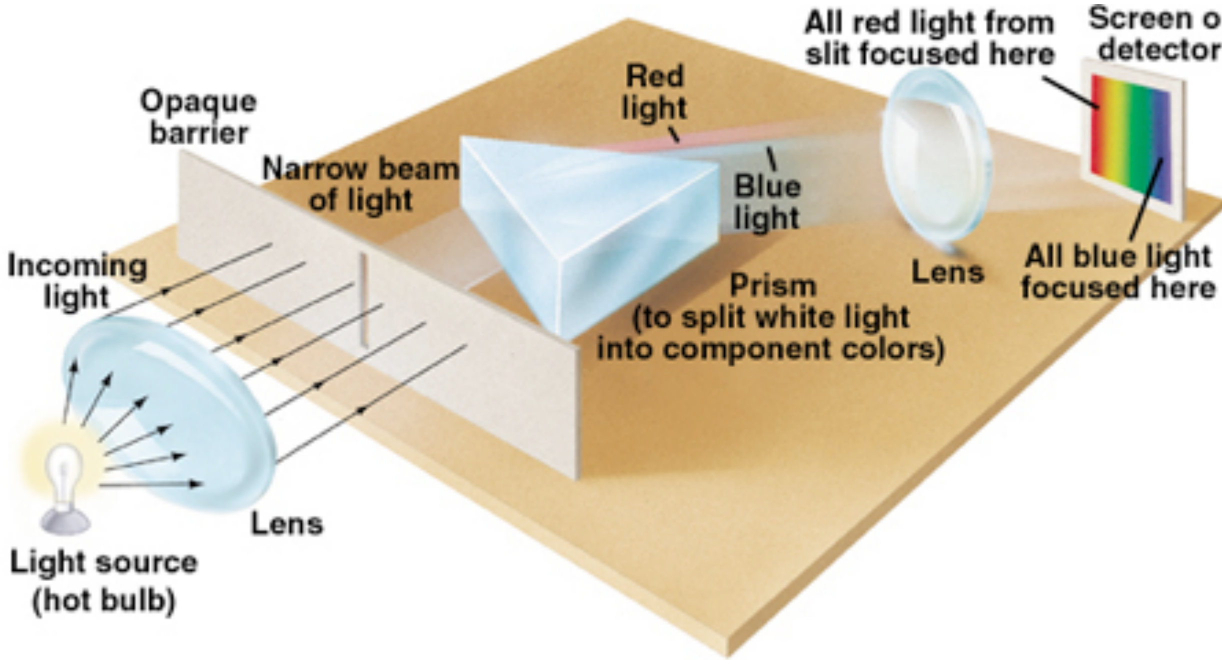
1845 William Parsons, Lord Rosse, in central Ireland erects a **72-inch aperture reflecting telescope**, with which he detects a new class of nebula: **spiral nebulae**. He also reports his success in resolving Orion into individual stars.

1851 Stephen Alexander suggests that the Milky Way may have a **spiral** structure.

1859 Wilhelm Bunsen and Gustav Robert Kirchhoff establish **spectrum analysis** on a firm basis; they state that

(1) glowing solids and liquids produce a continuous spectrum;
(2) glowing gases produce a bright-line spectrum;
(3) continuous spectra, when passed through a gas, become dark-line spectra.
(4) The line positions in both dark- and bright-line spectra are characteristic of the chemical constitution of the matter producing the lines; each element and compound has its characteristic spectrum; the element absorbs or emits light only of particular wavelengths. Consequently, the determination of the spectrum produced by an unknown substance will permit its chemical identification, if an identical spectrum is known to result from a body of already identified chemical composition.

Comment: What is a spectroscope? See the picture below.



Around 1670, Newton had discovered that a beam of sunlight if passed through a slit and then through a prism is broken up into a spectrum, an array of colors from red through violet, as in this diagram. In the early nineteenth century, scientists discovered that in fact various dark lines can be seen running from top to bottom in the spectrum. Gradually they learned that these lines were indicative of the chemicals present in the light source. This had many implications; not least one could determine the chemical makeup of our Sun. It was also learned that glowing gases give off spectra of a different form; these are **bright line spectra** with dark areas separating the lines.

1860s William Huggins attaches a spectroscope to his refracting telescope and determines using it that some nebulae give a **bright line spectrum**, indicating that they are glowing gases (and consequently cannot be island universes). He also determines a method using spectroscopy and the Doppler effect for light of determining whether glowing objects are moving toward or away from the Earth. This method allows determination of the velocity of the objects in the line of sight, i.e., their **radial velocity**.

1874 The astronomer Richard Proctor asserts: “All the nebulae hitherto discovered, whether gaseous or stellar, irregular, planetary, ring-formed, or elliptic, exist within the limits of the sidereal system. They all form part and parcel of that wonderful system whose nearer and brighter parts constitute the glories of our nocturnal heavens.” Probably the strongest reason for Proctor and others rejecting the island universe theory was the distribution of the nebulae, which cluster toward the poles of the Milky Way. From around this time until the second decade of the twentieth century, the **island universe theory was largely forsaken.**

1885 An extremely bright nova (new star) is observed near the center of Andromeda nebula. Before fading, this star, which was known as **S Andromedae**, rose to the 7th magnitude, that is, it became almost bright enough to be seen with the naked eye; in fact, it was about one tenth as bright as the entire nebula. Its brightness pointed to the conclusion either that Andromeda is quite near and not composed of stars or that S Andromedae surpasses all known stars in magnitude.

1887 Agnes Clerke in her *Popular History of Astronomy during the Nineteenth Century* declares: “There is no maintaining nebulae to be simply remote worlds of stars in the face of an agglomeration like the Nubecula Major [the larger Magellanic Cloud] containing in its (certainly capacious) bosom *both* stars and nebulae. Add the evidence of the spectroscope to the effect that a large proportion of these perplexing objects are gaseous, with the facts of their distribution telling of an intimate relation between the mode of their scattering and the lie of the Milky Way, and it becomes impossible to resist the conclusion that both nebular and stellar systems are parts of a single scheme.”

1899 J. E. Keeler of Lick estimates that he could photographically detect as many as **120,000 nebulae**. He also suggests that most nebulae are spirals.

Comment: It is important to understand that at this time astronomers had no way to determine the distances from us of astronomical objects outside our solar system. The first major breakthrough came in 1838 when Friedrich Bessel detected a parallax for one of the nearer stars. He did this by noting that over a year, the star slightly shifted its position. In fact, this shift was due to the motion of our Earth. This was the discovery of stellar parallax. To make this measurement, Bessel had to detect a shift about the size that we would see in a star 90 miles away if we walked through a circle of 2 feet diameter. Around 1900, about 300 stellar parallaxes (and thus stellar distances) were known. As we shall see, many of the results attained by astronomers leading up to the Expanding Universe Theory were dependent on measuring distances to remote objects, e.g., the nebulae.

Overall Situation in 1900

This historical survey of results attained by 1900 is designed to leave you with both a certain amount of information and also with a number of questions. You may be confused; in fact, astronomers during this period were themselves quite confused. One factor in this was that they had been forced to abandon many ideas that had seemed reasonable earlier

Nebulae: Throughout this period, this term was used to refer to various nebulous appearing objects. They typically look cloudy; in some cases, with good enough telescopes, they will be seen as a cluster of stars. Among such objects are the Orion nebula, Andromeda nebula, Messier 13, and the Magellanic Clouds. The last are a pair of huge nebulae in the southern celestial hemisphere, each being about 5° wide (ten times the diameter of the Moon). There was no good way of determining how far away any nebula was. The two chief theories as to their nature were (1) that they are collections of a huge number of stars gravitationally drawn to each other and immensely distant, possibly comparable in size and nature to the Milky Way galaxy, in which the Earth is located, or (2) glowing gases, which would be much nearer to us and far smaller than island universes, as the first group were called. Some of the spirals show a spiral form,

By 1900, astronomers had found a way to determine that some nebulae, e.g., Orion, are glowing gasses by using the spectroscope. Glowing gases give off bright-line spectra; star clusters give dark-line spectra as do stars. The consensus around 1900 was that all the visible objects were part of the Milky Way and that Island Universes do not exist. The Milky Way was assigned a width of about 30,000 Light Years in diameter. Moreover, one astronomer had estimated that 120,000 nebulae could be seen or photographed.

Regarding **stars**, by 1900 parallaxes had been found for about 300 stars, which allowed astronomers to assign distances to them.

Telescopes had greatly improved in size and functionality. It was becoming clear that astronomy in many ways was a part of physics, astronomy being aided greatly by photography and by spectroscopy.

Pressing **problems** were to determine the size and structure of the Milky Way and to learn whether it includes all that could be seen in the heavens. The idea of island universe had been set aside for the most part. In many ways, the key question was assigning **distances** to the objects seen, the key method being parallax measures. The base line for parallax measures was twice 93,000,000 miles (distance for the Earth to the Sun). Getting distances could reveal a great deal about the nature of the visible objects.

We now return to the chronology.

1908 The 60-inch-aperture reflecting telescope erected on Mount Wilson in California. This remained the largest reflector until 1917.

1911 Hugo von Seeliger, using statistical techniques, set the edge of the Milky Way at about 8,000 light-years from us. During this period, astronomers were assigning **diameters to the Milky Way in the range from 8,000 to about 30,000 light years.**

Comment: A **light year** is the distance that a beam of light travels in one year. Light rays move at the rate of 186,000 miles per second. From this point on, the light year will become our yardstick.

1912 Henrietta Swan Leavitt publishes her study of the Smaller Magellanic Cloud showing a period-luminosity relationship among the Cepheid variable stars in that object. Cepheid variable stars are stars that vary in brightness with periods from about one to about three hundred days and the light curve of which shows a characteristic pattern. This in principle provided a method for calculating the relative distance of any Cepheid that has an observable period. In particular, she finds that the longer the period of the Cepheid, the brighter it is. Because all these Cepheid variables were in the Smaller Magellanic Cloud, she concludes that distance is not a factor in how bright they appear and that consequently the relative distance of any Cepheid can be determined by comparing its brightness and period with the Cepheids in the Smaller Magellanic Clouds. This provides **a very powerful method of determining relative distances of any objects containing Cepheid variables**. Because no parallax had been found for any Cepheid, it was not possible to get absolute numbers for the distances of any of the Cepheids.

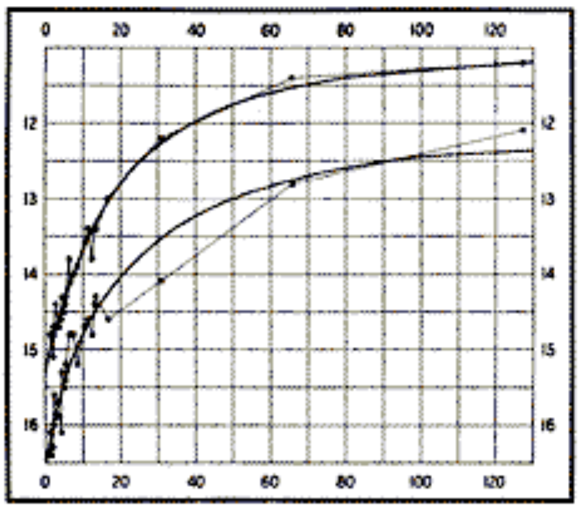


Fig. 1.

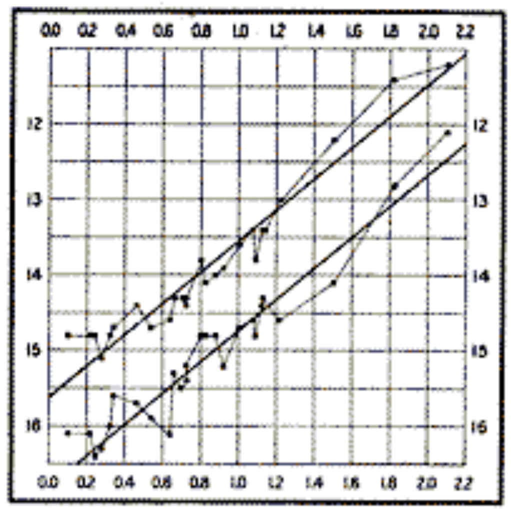


Fig. 2.

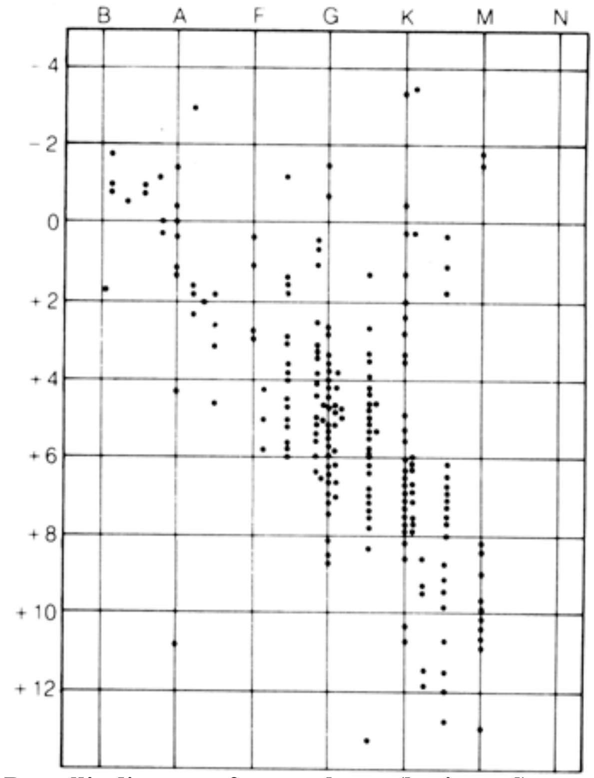
On the left, Leavitt's plot of the period in days (horizontal axis) of Cepheid variables in the Smaller Magellanic Cloud versus their magnitudes (vertical axis).
On the right, the plot is log of the period versus magnitude.

1912 Vesto Slipher of Lowell Observatory reports that the spectrum of the nebulosity surrounding the Pleiades is identical to that of the nearby stars; this indicates the existence of what have come to be known as **reflection nebulae**.

1913 Ejnar Hertzsprung makes the first attempt to determine a zero-point for the period-luminosity relationship of Leavitt, i.e., he attempts to affix absolute, not just relative values, to the scale that Leavitt had established. Because all the Cepheids were (and still are) beyond the reach of parallax measurements, he has to use approximation techniques. He uses a statistical method based on the observed proper motions and radial motions of 13 Cepheids. On this basis, he assigns a distance of 30,000 light-years to the Smaller Magellanic Cloud.

Comment: The **radial motion** of a star is how rapidly it is moving toward or away from us. It is measured by means of a spectroscope. It is measured in mile per hour. The **proper motion** of a star is the amount of angle that it traverses in some period of time, e.g, how many degrees it has covered in a year. What astronomers really way to determine is the direction and speed of the motion of an object, e.g., a star. This is somewhat different, but getting its proper motion and radial motion helps.

1913 Henry Norris Russell of Princeton publishes a paper presenting his **spectrum-luminosity diagram**. Russell shows that when the luminosities of stars (amount of light emitted) at known distances are plotted against their spectral types, they fall into a pattern resembling a reversed 7. This provides a rough method of determining the distances of stars located even far beyond the reach of parallactic methods. Diagrams in which the spectral types of stars are plotted against their luminosities are known as Hertzsprung-Russell diagrams, Hertzsprung having also developed the notion of comparing spectral type with luminosity. In this diagram, the stars at the left tend to be bluish in color, those at the right are reddish. The stars at the top are typically called giants, the stars at the bottom are dwarfs. This diagram showed that there are great variations in stars, but also indicated that there was a pattern in these variations. They are not scattered in a random manner. For example, bluish stars at the left tend to be very bright, whereas the red stars at the right may be either quite bright or relatively dim. This was a very important result.



Russell's diagram of spectral type (horizontal) versus luminosity (vertical)

1914 Jacobus Kapteyn notes that fainter stars, presumably at greater distances, show a reddening; this, he suggests, could be due to the presence of obscuring matter in space blocking blue rays.

1915 Vesto Slipher publishes a study of the radial velocities as measured spectrographically of **15 spirals**. He reports that these nebulae generally **have high radial velocities, on the order of 300 to 1100 km/sec**. He also reports that they are usually recessional velocities, that is, away from us.

Comment: We shall see that this is quite an important determination. These nebulae are at distances so large that no parallactic shift can be measured for them. Radial velocities are velocities in our line of sight. That is how he found they were typically moving at a high velocity and away from us.

1916 Adriaan van Maanen of Mt. Wilson Observatory where one of the best telescopes in the world was available reports observing a rotation of 0.02" per year in M101, a prominent spiral seen face on. He later reports rotations in other spirals. This suggests that the spiral nebulae are relatively near to us.

1916 **Harlow Shapley** of Mt. Wilson, who had been studying globular clusters (nebulae of circular form and brightest the center), argues that they are quite distant objects. Finding blue stars in them, indicating that despite their distance, little if any reddening had taken place, he urges in 1916 that Kapteyn's value for the effect of obscuring matter (about one magnitude per thousand parsecs) "must be from ten to a hundred times too large . . . and the absorption in our immediate region of the stellar system must be entirely negligible."


Harlow Shapley

1917 G. W. Ritchey of Mount Wilson reports his detection in a spiral nebula of a **nova** (a new star) that was visible at that time. Heber D. Curtis at Lick had already found three novae in earlier photographic plates of nebulae and publishes this fact after Ritchey's result is announced. Ritchey, Shapley of Mount Wilson, and others find additional novae. Curtis begins to investigate these novae in spirals as a possible criterion of distance. In 1917, he notes that of 27 known novae in our Milky Way, the average magnitude is 5.5, whereas novae in spirals are about 10 magnitudes dimmer, meaning that they are about 10,000 times dimmer. This suggests that **novae in spirals are about 100 times more remote than novae in the Milky Way.** He states: "The occurrence of these new stars in spirals must be regarded as having very definite bearing on the 'island universe' theory. . . ." S Andromedae, however, remains a problem.

1917 100-inch aperture reflecting telescope erected at Mount Wilson. It remains the largest reflector until 1948 when the 200 inch diameter Palomar reflector was completed.

1917 Heber Curtis, having observed **dark lanes on the edges of spirals** seen edge-on, suggests that were the Milky Way a spiral, it too would have dark lanes of obscuring matter. This obscuring matter would explain why no spirals are seen in the plane of the Milky Way.


Heber Curtis

By 1918 Shapley recalculates the zero point for the Cepheids, using a method similar to that used by Hertzsprung. On this basis, he calculates the distance of M13, the prominent globular cluster in Hercules, in which he had located Cepheids. Having determined the distance of M13 to his satisfaction and assuming that the other globular clusters are of comparable size, he estimates their distances by comparing their sizes and brightnesses to his figures for M13. He puts the globular clusters at distances from 20,000 to 200,000 light-years and urges that they define the shape of the galaxy and that most of these are clustered around the center of the galaxy. He argues that the **diameter of the Milky Way must be about 300,000 light-years** with the Sun located some distance from its center.

1919 Shapley argues that if spirals are Island Universes and if M101 is one-fifth the Milky Way's size (using his value for the Milky Way's size), then the rotation reported by van Maanen for M101 entails that the edge of M101 must be moving faster than the speed of light. This being contrary to the laws of physics, he concludes that M101 cannot be an Island Universe.

1919 E. E. Barnard of Yerkes Observatory publishes one of his many papers on the "Dark Markings" in the heavens. From many years observing such regions, he concludes that they are most probably due to obscuration by **clouds of dark matter** in interstellar space.

1920 Knut Lundmark of Sweden analyzes 22 novae found in Andromeda and set its distance on this basis at 600,000 light-years. Lundmark claims that S Andromedae, the very, very bright nova that had appeared in 1885, belongs to a **special class of novae** different from all novae previously observed in Andromeda.

1920 **The Great Debate**: Harlow Shapley and Heber Curtis debate on the size and nature of the Milky Way and on the question of island universes. Shapley claims that the Milky Way has a diameter of ca. 300,000 light years, about ten times larger than previously thought, but that there are no island universes. Curtis argues for a Milky Way diameter of ca. 30,000 light years, but claims that the spirals and so-called white nebulae are island universes, i.e., structures comparable to our Milky Way.

Comment: As should be evident, astronomers in this period were very confused about the overall structure and size of the universe. Various astronomers were reporting observations that contradicted what their colleagues were finding. From this point on, most of these were clarified. Note also that the confusions that beset astronomers were not just theoretical; they were encountering observations that contradicted other observations. This was because they were working right at the limits of what their instrumentation would provide. The good news is that from this point on, clarity begins to appear and they could determine what was true, what spurious. It is significant to note that these differences were not only theoretical; some of the observations contradicted other observations. This is not surprising in that the astronomers were working right at the limit of what their instruments would do.

1924 Edwin Hubble resolves the arms of Andromeda into individual stars and moreover locates Cepheid variable stars in Andromeda and two other nebulae. Using the Cepheids as a criterion of distance, he argues that many nebulae must be at island universe distances, e.g., a million or more light years distant. From this point on, astronomers in ever increasing numbers accept the **existence of island universes**, which astronomers now call galaxies.

Andromeda Nebula, now called Andromeda Galaxy

1929 Hubble collects data on the red shifts of various nebulae at by then known distances. These distances were known partly from finding Cepheids in them and partly from using the Hertzsprung-Russell diagram. On the basis of this (fairly limited) data, Hubble claims that the distances of nebulae are proportional to their red shifts, that is, to their radial velocities away from us. **This is the empirical basis for the idea of an expanding universe.** Hubble lays out what is has come to be called **Hubble's Law,** which is that for D the distance of a galaxy, V its velocity, and H a constant known as the Hubble constant, the following formula governs: V = HD. Hubble sets the value of H as about 500 km/sec per million parsecs. Its current value is about 75 km/sec per million parsecs.

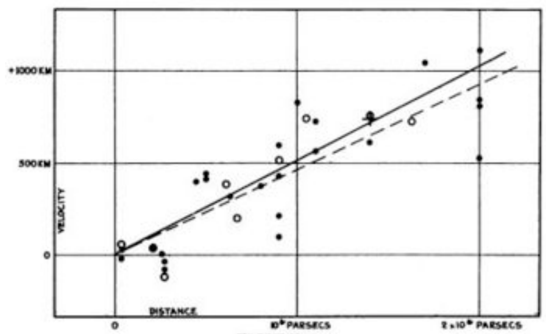


FIGURE 1
Velocity-Distance Relation among Extra-Galactic Nebulae.

Radial velocities, corrected for solar motion, are plotted against distances estimated from involved stars and mean luminosities of nebulae in a cluster. The black discs and full line represent the solution for solar motion using the nebulae individually; the circles and broken line represent the solution combining the nebulae into groups; the cross represents the mean velocity corresponding to the mean distance of 22 nebulae whose distances could not be estimated individually.

Comment: Red shifts? Recall the Doppler effect, an effect first discovered around 1850 in regard to sound. If a source of sound waves is moving away from us, the pitch of the sound gets lower, whereas if it is moving toward us, the pitch gets higher. This is because the distance between the pulses gets smaller. The same is true for light. If a source of light is moving away from us, the light appears more red; if toward us, more blue. Thus by examining the position of the spectral lines seen in a radiating object, astronomers could tell not only whether it is moving toward or away from us, but can also measure its velocity.

1930 Robert Trumpler carries out a study of open clusters, which he uses to show that there is **interstellar obscuring matter**. From that point on, astronomers accept the existence of substantial quantities of interstellar obscuring matter.

Comment: The Expanding Universe Theory emerged from the convergence around 1930 of two relatively separate lines of development, One of these was astronomical in that the persons working in this stream were typically astronomers who relied heavily on astronomical observations. The other line of development came mainly from theoretical physics and involved persons trained in physics and heavily involved in mathematics. So far, we have followed the first line of development; now we turn to the second.

Brief Chronology of the Theoretical Aspects of the Expanding Universe Theory

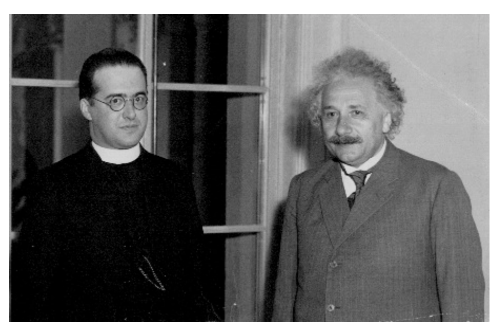
Albert Einstein

1916–17 **Albert Einstein** presents his **General Theory of Relativity** in papers published in these years. In working out his theory, Einstein finds that it entails that the universe must either be contracting or expanding. Because he believes that neither of these was the case, he adds a term, the "cosmological term," to his equations so as to make the universe static. This was a sort of fudge factor.

1922 The Russian mathematician **Alexander Friedmann** presents a paper based on Einstein's relativistic equations, but without the cosmological term, and shows that if the average density of matter in the universe is greater than $5 \bullet 10^{-30}$grams/cm^3, the universe should be contracting. On the other hand, were the average density less than this quantity, the universe would expand forever.

Georges Lemaître

1927 **Abbe Georges Lemaître** (1894–1966) publishes an important paper. Lemaître, a Belgian priest, who received his doctorate in physics in 1920 from Louvain University, where he eventually taught, had also studied at Cambridge University with Arthur Stanley Eddington and at Harvard College Observatory. Lemaître, although trained mainly in mathematical physics, was also very interested in astronomy. In his 1927 paper, Lemaître puts together Einstein's relativistic equations with Slipher's observations of red shifts in spiral nebulae (galaxies) indicating their motion away from us, to formulate what is called the **Expanding Universe** or **Big Bang** theory,[2] according to which matter was originally all together in one small area. His paper, published in a little known journal, does not at first attract much attention.



Lemaître and Einstein in 1933

1927 The Fifth Solvay Congress of eminent physicists meets in Brussels, Belgium, six months after the publication of Lemaître's paper. Einstein was among those attending. During a break in the conference, Einstein meets in a park with the Belgian priest. Einstein tells Lemaître about Friedmann's paper and Lemaître informs Einstein about his paper. Einstein's response: "Your calculations are correct, but your physical insight is abominable."

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[2]The term "expanding universe" is the more comprehensive term. Big Bang theories are particular versions of the general expanding universe theory, i.e., big bang theories claim that the expansion began in a small area at a definite point in time. In fact, the term "big bang" was first introduced in 1949 by Fred Hoyle, an opponent of the theory, who employed it in a derisive sense. Lemaître adopted the term "primeval atom" to describe his version of the theory.

1928 Lemaître meets Willem de Sitter at the General Assembly of the International Astronomical Union in Leiden, but de Sitter takes no interest in the paper by Lemaître, who as yet was almost unknown.

1930 January meeting of the Royal Astronomical Society in London. Attending were Willem de Sitter, who happened to be in London, and Arthur Stanley Eddington, the leading British expert on relativistic cosmology. During the meeting, de Sitter is invited to discuss his research. He comments that he is dissatisfied with his model, both because it could not explain the movement of the nebulae as reported by Hubble and because it was evident that the universe is not empty. Eddington asks whether besides the Einstein and de Sitter universes, others may not be possible. He suggests that although these two universes are static, it may be possible to formulate a universe that is in motion. This discussion gets published in the minutes of the meeting. Lemaître sees this report and writes Eddington reminding him that in 1927 he (Lemaître) had published a paper that takes a dynamic approach. In fact, there is substantial indication that Lemaître had sent a copy of his paper to Eddington. Then in 1930, Eddington sees the light, writing to de Sitter that Lemaître's paper "seems a complete answer to the problem we were discussing." In response, de Sitter calls the paper "ingenious." Eddington proceeds to have a translation of Lemaître's paper published in the March, 1931 issue of the *Monthly Notices of the Royal Astronomical Society*. Gradually, Einstein, Shapley, and most cosmologists accept Lemaître's brilliant analysis.

1931 Eddington publishes a long paper titled "The End of the World: From the Standpoint of Mathematical Physics." In it, he states: "Philosophically, the notion of the beginning of the present order of Nature is repugnant to me." Lemaître sends a very short response titled "The Beginning of the World from the Point of View of Quantum Theory," in which Lemaître sets out his "primeval atom" claim; as he states, "we could conceive the beginning of the universe in the form of a unique atom, the atomic weight of which is the total mass of the universe. This highly unstable atom would divide in smaller and smaller atoms by a kind of super-radioactive process."[3] He elaborates his ideas in a follow-up paper, where he states: "A complete revision of our cosmological hypothesis is necessary, the primary condition being the test of rapidity. We want a 'fireworks' theory of evolution. The last two thousand million years are slow evolution; they are ashes and smoke of bright but very rapid fireworks."[4] He also states: "If the total time of evolution did not exceed, say, ten times that age of the earth, it is quite possible to have a variation of the radius of the universe going on, expanding from zero to the actual value. I would picture the evolution as follows: at the origin, all the mass of the universe would exist tin the form of a unique atom; the radius of the universe, although not strictly zero, being relatively very small. The whole universe would be produced by the disintegration of this primeval atom."[5]

Comment: Various scientists, especially Einstein, were hesitant about the idea of the universe beginning in time, the problem for Einstein being theological. He and Lemaître at one point in

[3] *Nature*, 127 (May 9, 1913), 706.
[4] *Nature*, 127 (Oct. 24, 1913), 705.
[5] *Nature*, 127 (Oct. 24, 1913), 706.

the early 1930s discussed Lemaître's claim that the universe began in time, Einstein responding: "No, not that, it smells too much of creation."

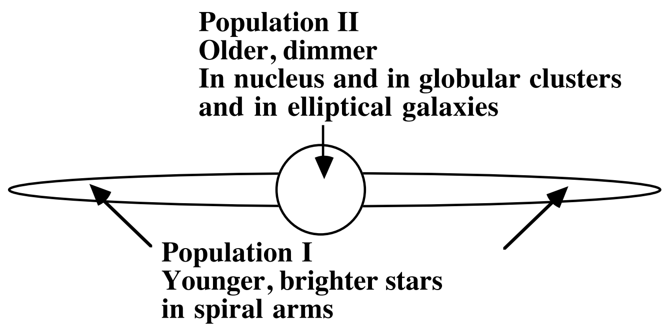
Comment: Some authors suggested that Lemaître may have been influenced in coming to this idea by theological concerns. He denied this. It is clear that some scientists, for example, Hoyle, resisted the expanding universe theory partly because it is compatible with the Christian idea that the universe had a beginning in time.

1931 Albert Einstein drops his cosmological term, later stating that his introduction of it was his "greatest blunder."

Comment: Overall, by this time, the Expanding Universe Theory had begun to win over a number of key supporters, but it was also beset by various problems and challenges. One challenge was determining the value of the Hubble Constant, which is the ratio between the distance of a spiral nebula and its speed away from the Earth. The biggest problem was determining the distance of the spirals. Recall that the spirals were giant galaxies far beyond the Milky Way. For example, Andromeda Galaxy, one of the nearest, is 2.5 million light years distant.

The Expanding Universe Theory after 1931

1942 Walter Baade at Mt. Wilson Observatory argues for the existence of two types of stars, **Population I** and **Population II type stars** (see diagram).



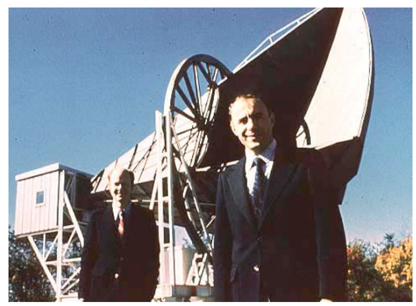
1940s Early in the 1940s, geological studies of radioactive elements in rocks indicate that the age of the Earth should be about 3.5 billion years. This conflicts with the estimate of the age of the universe based on the value that Hubble had assigned the Hubble constant, i.e., 500 kilometers per sec per million parsecs. From this value and from the assumption that all the matter in the universe had initially been in one small area when an explosion set it flying apart, one could calculate the age of the universe as about 2 billion years. This creates an obvious problem because it made the **age of the universe** less than the **age of the Earth**!

1946–53 During this period, various scientists including George Gamow, Ralph Alpher, Robert Hermann, and Fred Hoyle work out the physics and chemistry of the early universe, in particular, the nuclear processes that led from the earliest stages of the Big Bang to a universe containing the elements of the periodic table. This is the period of understanding of **nucleosynthesis**. It was done in terms of the Big Bang theory, which increased the confidence that the scientific community thereby had in the correctness of the Big Bang cosmology.

1948 Three very gifted British scientists Fred Hoyle, Hermann Bondi, and Thomas Gold put forth the **Steady State theory** of the universe in opposition to the Expanding Universe theory. Like Lemaître’s theory, it was compatible with Einstein’s General Theory of Relativity. According to this theory, matter in the form of hydrogen atoms is continuously created in interstellar space, which keeps the density of the universe constant. The Steady State theory, unlike the Expanding Universe theory, does not entail that the universe had a beginning. It does accept the claim that the galaxies are flying apart from each other.

1952 Walter Baade based on observations with the Palomar 200–inch telescope concludes that there are **two types of Cepheid variables**, Type I and Type II, which have somewhat different Hertzsprung-Russell diagrams. This leads to a major revision in the Hubble constant and of the age of the universe.[6]

1965 The development that effectively ends the debate between the expanding universe and steady state theories occurs in 1965. **Arno A. Penzias and Robert W. Wilson,** both of Bell Telephone Laboratories in New Jersey, modify a very sensitive antenna that had been devised to receive signals at 7.35 cm. wavelength from the Echo satellite. Using this device, they detect very weak short-wave radiation, which turns out to be far more intense than they had expected and to come from all directions of the sky. They at first have no clear idea of what could be causing this radiation.



Simultaneously and about 30 miles away at Princeton University, Robert Dicke concludes on theoretical grounds that just such a radiation must exist and begins to devise experiments that he hopes will verify its existence. Thus Penzias and Wilson have an effect, and are searching for its cause, whereas Dicke, having a hypothetical cause, is puzzled as to how to detect an effect. Penzias and Wilson hear of Dicke’s interest and meet with him, eventually collaborating on experiments to remeasure at 3.2 cm. This wavelength is characteristic of very cold sources, at 3° K (3° Kelvin, i.e., 3° above absolute zero). As early as the 1940s, George Gamow had predicted the existence of such a radiation, known as the “**3°K background radiation**.” Scientists see the detection of this radiation as strongly confirming the Big Bang theory and falsifying the steady state theory.

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[6] You may wonder how the age of the universe is calculated. Consider the relative motion of two objects from the time of the big bang until the present. The time required for this distance to open up will be the age of the universe. The time must equal the distance separating the two objects divided by the recessional velocity that is acting to separate them.

$$\text{Age} = \text{Time since Big Bang} = \frac{\text{separation distance}}{\text{recessional velocity}}$$

But Hubble’s law is that recessional velocity = H•separation distance, where H is the Hubble constant. Divide both sides of this last equation by separation distance. This gives that $H = \frac{\text{recessional velocity}}{\text{separation distance}}$.

From this it is clear that $\frac{1}{H} = \frac{\text{separation distance}}{\text{recessional velocity}}$, which is equal to the Age.

If H = 75km/s/million parsecs, then $\text{Age} = \frac{1}{\text{75km/s/million parsecs}} = 13$ billion yrs.

If H = 500km/s/million parsecs, then $\text{Age} = \frac{1}{\text{500km/s/million parsecs}} = 2$ billion yrs.

In short, $\text{Age} = \frac{D}{V}$ and $V = HD$, which implies $\frac{1}{H} = \frac{D}{V} = \text{Age}$. Then substitute value for H.

1966 Death on June 6 of Georges Lemaître, who had lived to see the final acceptance of his theory of the universe.