1

The Search

Five Turning Points

In September of 1608 a Dutchman at the annual fair in Frankfurt offered for sale “an instrument by means of which the most distant objects might be seen as though quite near.”[1] On October 2, not a month later, the States-General of the Netherlands recorded in The Hague the patent application for a similar instrument by Hans Lipperhey, a spectacle maker from Middelburg in Zeeland. But there were several competing claims and no patent was awarded. By April, 1609, spyglasses could be bought in the shops of spectacle makers in Paris, and by that summer Thomas Harriot in England was using a spyglass to make observations of the moon and was drawing maps of its surface.[i]

In Italy, Galileo Galilei, an experimenter of the greatest skill who had previously invented an improved military compass, also went to work. He constructed a spyglass which he presented to the Venetian senate in August of that year, pointing out that its ninefold magnification could prove of utmost importance in war. Galileo then undertook the construction of an even more powerful instrument that magnified some 20 times and incorporated a number of improvements in design. Although he had regularly lectured on the Ptolemaic system at the University of Padua and given public lectures on the supernova of 1604, Galileo’s work up to that time had largely been concerned with the laws of moving bodies and with practical inventions. Now, however, he entered observational astronomy with exuberant energy. He aimed his spyglass —the word *telescope* was not to be coined until the following year—at the moon,

[i] Technical terms used in this book and abbreviations that may be foreign to readers are explained in the Glossary/Index at the end of the book.

stars, and planets and quickly discovered four of the moons orbiting Jupiter, found the surface of our own moon to be covered with mountains and valleys much like Earth's, and in these ways immediately elucidated the general nature of moons. Turning to the Milky Way, Galileo noted that there were vastly larger numbers of stars than ever seen before: Viewed through his spyglass the milky patches condensed into swarms of stars.

These results Galileo described in his *Sidereus Nuncius*—roughly translated as *The Sidereal Messenger*, or *The Starry Messenger*.[2] This booklet, published in March, 1610, is so short it can be read in an hour. But its reports of Galileo's findings caused an immediate furor among the learned of the day and started a revolutionary era of astronomical discovery.

At six o'clock on the morning of August 7, 1912, the Austrian physicist Viktor Hess and two companions climbed into a balloon gondola for the last of a series of seven launches. The flight, which had started at Aussig on the Elbe, was under the command of Captain W. Hoffory. The meteorological observer was W. Wolf, and Hess listed himself as "observer for atmospheric electricity." Over the next three or four hours the balloon rose to an altitude above 5 kilometers, and by noon the group was landing at Pieskow, some 50 kilometers from Berlin. During the six hours of flight Hess had carefully recorded the readings of three electroscopes he used to measure the intensity of radiation and had noted a rise in the radiation level as the balloon rose in altitude.

In the *Physikalische Zeitschrift* of November 1 that year Hess wrote, "The results of these observations seem best explained by a radiation of great penetrating power entering our atmosphere from above . . . "[3] This was the beginning of cosmic-ray astronomy. Twenty-four years later Hess shared the Nobel Prize in physics for his discovery.

Late in 1931 Karl Jansky, a radio engineer at Bell Telephone Laboratory, set up an observing station at Holmdel, New Jersey, to track down the source of static noise that interfered with transoceanic radio telephone reception. He was particularly interested in short radio waves and built an antenna tuned to a wavelength of 14.6 meters. In records kept day after day, three sources of noise soon became apparent. Local thunderstorms were the most obvious. More distant thunderstorms seemed to provide a second source. A third source gave a steady hiss that varied with the time of day. At first Jansky thought he was seeing radio emission associated with the sun. In a 1932 paper in the *Proceedings of the Institute of Radio Engineers* he wrote:

> During the latter part of December and the first part of January the direction of arrival of this static coincided, for most of the daylight hours,

> with the direction of the sun from the receiver. However, during January and February the direction has gradually shifted so that now (March 1) it precedes in time the direction of the sun by as much as an hour.[4]

In a footnote inserted in proof Jansky adds, "Since this paper was written the curve has shifted much further to the left. Now (May 25) it crosses south at 4:30 A.M."

A year later Jansky was almost sure that this radiation was arriving from the central portions of the Milky Way. The directional discrimination of his equipment, however, was not sufficiently accurate, and he noted in a second paper in the *Proceedings* that the direction of peak radio emission "is also very near the point in space toward which the solar system is moving with respect to other stars."[5] Jansky's surmise about the Milky Way was, however, to prove correct, and he is credited with the initiation of radio astronomy. Subsequent technical strides have permitted the discovery of radio galaxies that are far more powerful emitters of radio waves than the Milky Way. These techniques have also led to the disclosure of quasars, pulsars, interstellar masers, and many other surprises.

In 1948 a group of researchers at the U.S. Naval Research Laboratories (NRL) began to place X-ray detectors aboard German V-2 rockets captured at the end of World War II. On the earliest flights, the physicist T. R. Burnight used simple detectors consisting of photographic films covered by thin metal plates. With a rocket launched at White Sands, New Mexico, on August 5, 1948, he observed solar X rays that could penetrate through beryllium plates three-quarters of a millimeter thick.[6] This flight provided evidence for X-radiation in unexpected intensities. A few months later Burnight's colleagues, Richard Tousey, J. D. Purcell, and K. Watanabe, confirmed these observations.[7] And on September 29, 1949, Herbert Friedman, S. W. Lichtman, and E. T. Byram, also of NRL, were able to launch a V-2 payload containing modern photon counters that would usher in a whole new era of X-ray astronomy.[8]

The sun is a weak X-ray source. It would not have been detected had it been at the distance of other stars; and for a decade no one expected to find X-ray emission from stars other than the sun. By 1960, however, theoretical predictions made the detection of X rays from supernova remnants, from flare stars, or from a hot extragalactic plasma distinct possibilities.

With a payload designed mainly to search for X rays generated at the surface of the moon by energetic radiation arriving from the sun, Riccardo Giacconi, Herbert Gursky, Frank Paolini, and Bruno Rossi of the American Science and Engineering Corporation, in 1962, detected the first signals from an X-ray source outside the solar system. Soon the NRL team, led by Herbert Friedman, accurately located the position of this source. It lies in the constellation Scorpius.[9] Like other X-ray stars it is now known to be a member of a close binary. Later, improvements in resolving power led to the identification of X-ray emission from galaxies and clusters of galaxies and showed the existence of rapidly pulsing emission from one variety of X-ray stars.

In an age of mistrust among nations, extreme measures are taken to keep track of weapons tests carried out by other countries. During the 1960s the United States placed the *Vela* series of spacecraft in distant orbits around Earth. They were deployed to leave no part of our planet unsurveyed at any time. Each spacecraft had the capability of detecting bursts of gamma rays—energetic X rays—generated in nuclear explosions in space.

In mid-1973 Ray W. Klebesadel, Ian B. Strong, and R. A. Olson at the Los Alamos Scientific Laboratory, New Mexico, surprised astronomers everywhere by announcing that short bursts of gamma rays lasting only a few seconds had been observed by several of the spacecraft and appeared to arrive from beyond the solar system.[10] Bursts of considerable strength appear to occur four or five times a year, but we know little else of this phenomenon.

Questions

The search for cosmic phenomena is one of mankind's grandest adventures and one of the most ambitious enterprises of modern science. To understand its conduct we will need to discern the nature of the phenomena, identify the men and women caught up in the search, describe the skills these scientists possess, analyze the plans they follow to their goals, and identify the tools required for their quest. We will need to know how the most significant discoveries are being made, whether past successes can guide us to further discoveries, whether there are ways to gauge the future scope of the search—of deciding whether our inventory of cosmic phenomena is nearly complete, whether we are close to being the last generation of astronomers needed to unravel the complexities of the universe, or whether there will be an endless cadre of cosmic researchers stretching into an uncertain future.

There is only one way to approach this study: We must look at the conduct of past searches in order to discern trends that can lead to assessments of the future.

Later on we will examine many other astronomical searches. The five turning points just presented, however, illustrate a number of common trends.

Trends

Seven traits common to many discoveries, particularly to those just cited and to others listed in figure 1.1, and more carefully analyzed in table 5.1 of chapter 5, are these:

1. *The most important observational discoveries result from substantial technological innovation in observational astronomy.*

Galileo's spyglass enabled him to resolve features on the moon considerably finer than any that can be distinguished with the unaided eye. He could also see stars several magnitudes fainter. Viktor Hess's discovery of cosmic rays led to an increasing awareness that electromagnetic radiation is not the only carrier of astronomical information reaching Earth; there also exist energetic subatomic particles that inform us about catastrophic events far away in the cosmos.

Karl Jansky looked out into the universe and saw signals from our galaxy at wavelengths 20 million times longer than anything the eye can see; the scientists at the Naval Research Laboratory and at the American Science and Engineering Corporation were able to detect signals at wavelengths 1,000 times shorter than visible light, and these techniques led to the discovery of X-ray stars and galaxies. The Vela military satellites could detect brief bursts of gamma rays and found just such bursts arriving from unknown parts of the sky; and short pulses detected at radio wavelengths similarly had led to Anthony Hewish and Jocelyn Bell to the discovery of pulsars in 1968.[11]

Technological innovations that led to discovery have usually involved completely new wavelength ranges never used in astronomy before, or have made use of instruments with unprecedented precision for resolving sources to exhibit structural features, time variations or spectral features never seen before. Mere telescope size—light-collecting area alone—appears not to have been crucial to discoveries. Relatively few discoveries have been made with the largest telescope in existence at the time.

2. *Once a powerful new technique is applied in astronomy, the most profound discoveries follow with little delay.*

Many discoveries are made within weeks or months of the introduction of new observing equipment. In the past twenty-five years there have been no discoveries that could have been made with instruments available a quarter-century earlier; and only a few of these recent findings could have been established as little as ten years earlier (figure 1.2). Occasionally a discovery is verified by an observer who can point to records he had obtained some two or three years before; on these the new phenomenon may already be discerned, though not perhaps convincingly enough to stand out.

3. *A novel instrument soon exhausts its capacity for discovery.*

This corollary to the speed with which new discoveries follow technical innovations does not imply that new apparatus quickly becomes useless. It just means that the instrument's function changes. It joins an existing array of tools

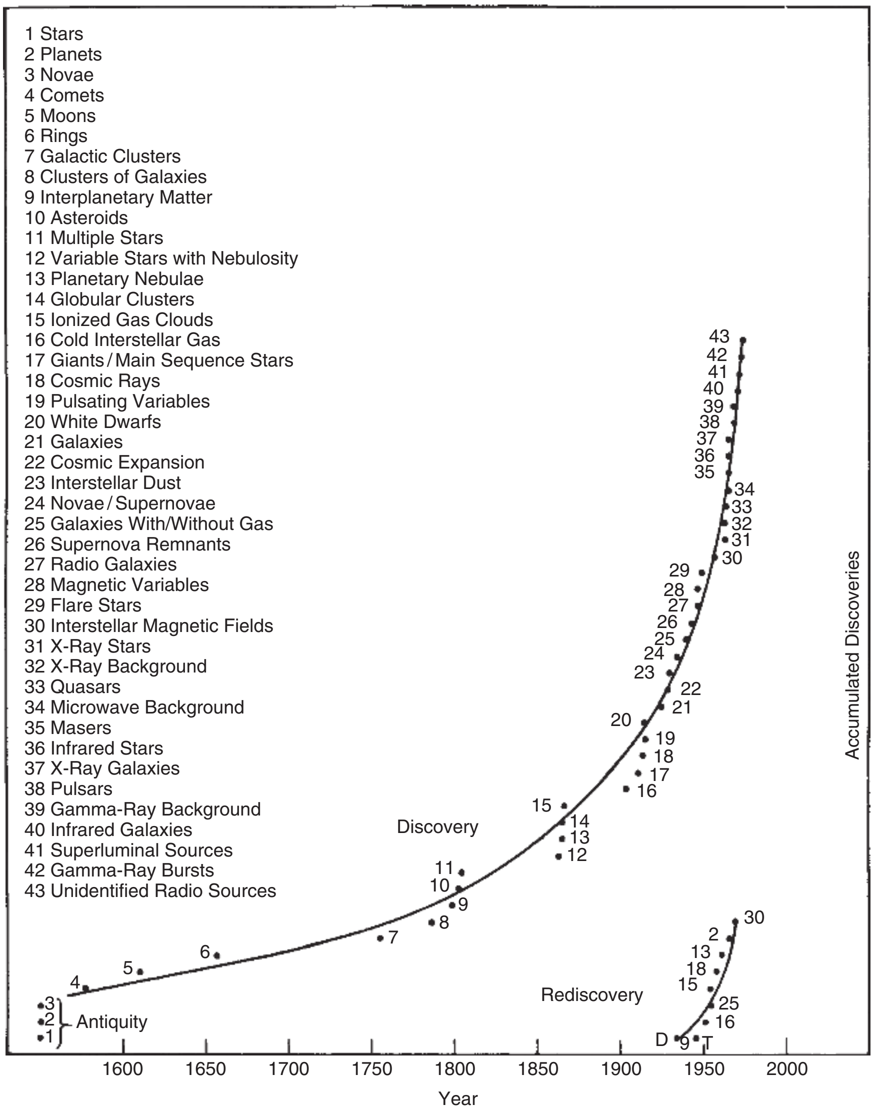

Figure 1.1 Discovery and Rediscovery Dates for 43 Cosmic Phenomena, Showing Progressive Accumulation
Though there is no unique definition of a cosmic phenomenon, most astronomers would compile a list much like the one shown here if asked to name the principal phenomena characterizing the universe. The 43 phenomena named are given prominence in most astronomical texts and standard reference works. Conferences and symposia concern themselves with individual phenomena on the list, and books or review articles frequently focus on one or another of these entries.

The discovery dates for the phenomena shown in the top curve cannot always be precisely pinpointed because the realization of a discovery sometimes dawns slowly.

available to the astronomer for analytical work, rather than for discovery, and continues useful service in that capacity.

To revitalize a technique for further searches for new phenomena, its sensitivity or resolving power must be substantially increased, often by as much as several factors of 10. Thus the discovery of quasars became possible only after radio astronomical techniques had advanced to a stage at which sources subtending angles no larger than 1 second of arc could be identified and accurately located in the sky.[12] The radio equipment available earlier to Jansky could simply not have coped with such observations.

4. *New cosmic phenomena frequently are discovered by physicists and engineers or by other researchers originally trained outside astronomy.*

In a wide-ranging study of the emergence of radio astronomy in Great Britain, the sociologists David Edge and Michael Mulkay have noted that all of the early British radio astronomers were physicists or electrical engineers and that radio astronomy, worldwide, was originally staffed largely by workers trained in physics or electrical engineering.[13] The same trait can be discerned all across modern astronomy. We speak of "cosmic-ray physicists," and, in fact, cosmic-

Caption for Figure 1.1 (cont.)

Where possible, however, the year of discovery is taken to be the year in which the first unambiguous report of the discovery is published.

At times a discovery involves the recognition that a previously known phenomenon actually comprises two quite distinct sources or classes of events—giant and main sequence stars, novae and supernovae, galaxies that contain gas while others do not. Such discoveries are indicated by a slash (/) in the designation of the two phenomena that become resolved.

The lower curve shows phenomena that are redundantly recognized through two totally independent techniques. Thus, the existence of planets in the solar system would by now have been discovered even if optical telescopes had never been invented. An astronomer on an ever-cloudy body, such as Venus, would by now also have discovered the system of planets by virtue of planetary radio emission alone.

One phenomenon, interplanetary matter, is known not only in doubly (D) but in triply (T) independent ways. We see the faint zodiacal light in the night sky; we observe meteors and meteorites burning as they enter the atmosphere and can collect meteorites that hit the ground; finally, we obtain radar reflections from fine dust grains that burn on entering the upper atmosphere.

The most striking aspect of the two curves is the increasingly accelerated rate of discovery shown by the rapid rise in the top curve. Simultaneously with this rise comes an increasing recognition of previously known phenomena, now rediscovered by means of radio telescopes. Soon we may recognize many of these phenomena independently, in yet other ways—by means of the X-ray, infrared, or perhaps neutrino signals they emit.

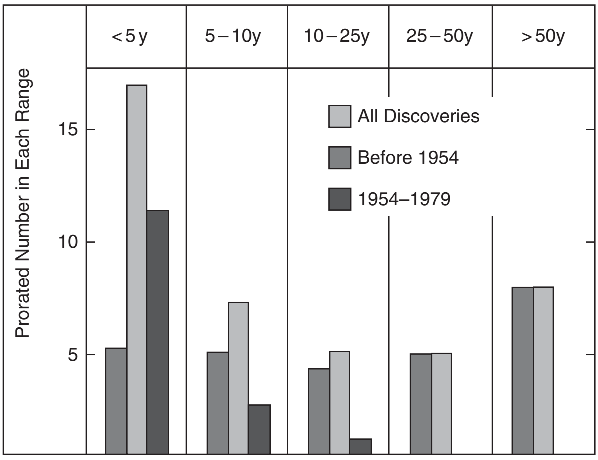

Figure 1.2 Age of Required Technology at Time of Discovery for 43 Cosmic Phenomena

It is not surprising that a cosmic phenomenon cannot be discovered until technical means exist that make the discovery possible. An X-ray star cannot be discovered unless we construct telescopes sensitive to X rays; bursts of gamma rays reaching us from the universe will not be noticed unless apparatus capable of sensing these rays is taken above the atmosphere to perform the observation. What is surprising, however, is the speed with which major discoveries follow technical innovation. This is particularly striking in recent times.

A large fraction of the 43 phenomena listed in figure 1.1 was discovered less than five years (<5yr) after the introduction into astronomy of those techniques essential to the discovery. Prior to 1954 the time lag between innovation and discovery tended to be longer and the rate of discovery shown in figure 1.1 was slower as well.

For many of the discoveries the recognition of the new phenomenon, or its rediscovery by independent means, occurred in a series of discrete steps. For these the age of the contributing technology was separately assessed for each step and prorated to keep the total at 43.

ray research is largely carried out in the physics departments of universities. Similarly, none of the early X-ray or gamma-ray astronomers appear to have had advanced degrees in astronomy. Most of them had been trained as physicists.

This trend is not just confined to modern times. We need only think of the work of Galileo, William Herschel, Joseph Fraunhofer, and E. C. Pickering, who brought new methods and techniques to astronomy after working in other fields (see figure 1.3). Many of these pioneers initially worked at what professional astronomers would have considered the outskirts of astronomy. They could at best be marginally considered astronomers; and Edge and Mulkay have termed them *marginal* workers.[14] The rapid expansion of astronomy since World War II

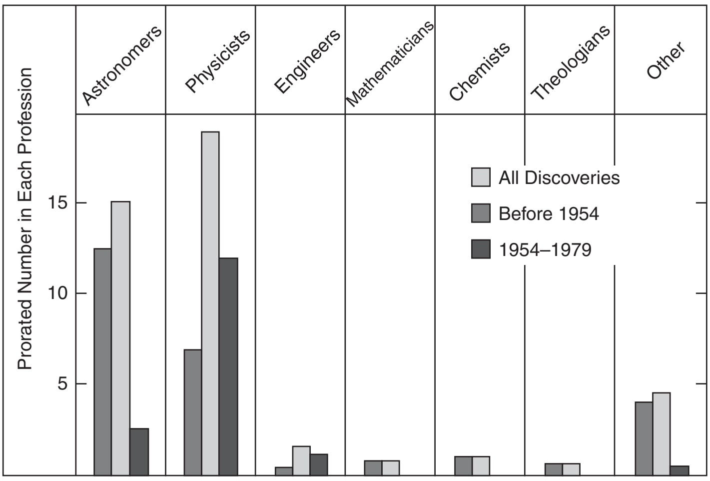

Figure 1.3 Career Background for the Discoverers of 43 Cosmic Phenomena
Most of the major cosmic phenomena were discovered by individuals prepared for careers other than astronomy—instrumentalists with novel techniques for looking at the sky. This educational background and early work experience outside astronomy is particularly apparent for the twenty-five-year period between 1954 and 1979. Even prior to 1954, however, half of all discoveries were made by outsiders. Both original discoveries and rediscoveries of phenomena listed in figure 1.1 are included in this compilation. Where several discoverers were involved, the contributions are prorated so that the number of careers also totals 43.

by now has greatly extended earlier boundaries so that radio observers, as well as infrared, X-ray, and gamma-ray astronomers, now find themselves at the center of current astronomical activity, though twenty years ago they all were marginal.

5. *Many of the discoveries of new phenomena involved use of equipment originally designed for military use.*

The rapid development of radio astronomy after World War II was made possible by existing radar equipment developed for the war effort.[15] Even before the war's end, however, James Stanley Hey, at the time a young troubleshooter for the British radar network, had noted occasional strong radio emission from the sun[16] and had discovered radar reflections from meteor trails.[17] Subsequently both solar radio astronomy and radar meteor observations developed into subdisciplines with their own practitioners. In 1946, shortly after the end of the war, Hey and his collaborators, still using wartime equipment available to them, also discovered a curiously undulating cosmic radio signal that proved to be the first extragalactic radio source, Cygnus A.[18]

In the United States the earliest postwar solar X-ray and far-ultraviolet observations were carried out with German V-2 rockets. Advances in infrared astronomy were similarly based on progress in the construction of military detectors, but the most sensitive far-infrared detectors were not developed until some time after the war and did not become available for astronomical work until the late 1950s and early 1960s.

This relationship between the tools of surveillance in war and in astronomy is not new: Galileo had pointed out the military value of the spyglass to the Venetian senate. His gift of the spyglass so pleased the senators that they at once doubled his salary and made his professorship at the University of Padua a lifetime appointment.[19]

The same interdependence of scientific and military progress can be found in a variety of fields. Many of the urgent problems in navigation, communication, detection, logistics, and medicine, as well as in willful destruction, have occupied military minds throughout the centuries, and it is not surprising that pure science and constructive technology often inherit some gains. As early as 1938, the sociologist Robert K. Merton noted this longstanding relationship in his study *Science, Technology and Society in Seventeenth-Century England.*[20] Astronomy has benefited most directly from attempts to advance the arts of navigation, communication, and detection.

6. *The instruments used in the discovery of new phenomena often have been constructed by the observer and used exclusively by him.*

The instruments used by Galileo, Hess, Jansky, and the early X-ray astronomers were built by them and were under their sole control. The Los Alamos group that discovered gamma-ray bursts had access to all the data gathered by the passive Vela satellites. Men like Christian Huygens, James Bradley, William Herschel, Friedrich Wilhelm Bessel, William Huggins, and William Parsons, third earl of Rosse, responsible for prime discoveries in the seventeenth, eighteenth and nineteenth centuries, also had instruments that they alone might use: When faced with a surprising result, they could check their apparatus at leisure, repeat the observations, and cross-check their results until they were certain that a finding was genuine and not due to some instrumental artifact. More than half of the phenomena discovered in historical times were made with instruments under exclusive control of the astronomers responsible for the discovery.

At national centers, equipment is widely shared among both resident and visiting astronomers. These centers were first established in the United States in the late 1950s, and by now require two-thirds of the National Science Foundation's astronomy budget for their support. None of the forty-three