THE COSMIC CLUE

For centuries sky watchers wondered about the nature of "nebulous stars." We now call them galaxies — vast star systems far beyond our own

BY WILLIAM J. BROAD

Now, my suspicion is that the universe is not only queerer than we suppose, but queerer than we can *suppose.*
—J.B.S. Haldane

On a moonless night in autumn, when thousands of stars dance overhead, a person with average eyesight can spot a vague patch of light near the center of Andromeda, the constellation of the chained princess. It is clearly not a star. Spread into a long oval, it contains no sharp point of light. Simon Marius, a contemporary of Galileo, wrote that it resembled "the light of a candle which one sees from a distance in the night through a piece of transparent horn."

Strewn at random across the night sky, several other vague patches like the one in Andromeda are visible to the naked eye. For Galileo, the mystery of these "nebulous stars" was solved once and for all in 1610 when he turned his telescope on the sky for the first time. "The stars," he later wrote, "which have been called nebulous by every other astronomer up to this time turn out to be a group of very small stars arranged in a wonderful manner." It was idle boast. True, Galileo's telescope *could* resolve many of the patches into myriads of stars. And the "whitish clouds" of the Milky Way were seen by Galileo to be "nothing but a congeries of innumerable stars grouped together in clusters." But there remained many whorls of light, including the hazy patch in Andromeda, that would not explode into countless stars for Galileo — or for his heirs equipped with more and more powerful telescopes.

By the dawn of the 20th century, thousands of nebulae in a host of shapes and sizes had been discovered. Most interesting were the small spirals, which, no matter how high the magnification, would not resolve into clusters of individual stars. Since most astronomers at the time believed that the Milky Way was *the* galaxy, encompassing all celestial bodies, they thought the mysterious spiral nebulae were swirls of interstellar gas. They were wrong.

One man, working with the new 100-inch Mount Wilson telescope from 1919 to 1924, fractured for all time the old picture of the universe. Edwin Hubble set about measuring the distances to the spiral nebulae and, to the awe of astronomers and laymen alike, proved that they were actually other galaxies — vast star systems far beyond our own.

The vague patch in the constellation Andromeda was no mere whisp of interstellar flotsam. To Hubble, and to astronomers ever since, it became an independent galaxy, probably somewhat larger than the Milky Way, and made up of at least 300 billion stars. In plotting the distances to other galaxies, Hubble found that Andromeda was our nearest galactic neighbor (except for the Magellanic Clouds, which are companions of the Milky Way). But "near" is perhaps deceptive. According to Hubble's calculations, the light we now witness from the galaxy in Andromeda started out on its intergalactic voyage some two million years ago.

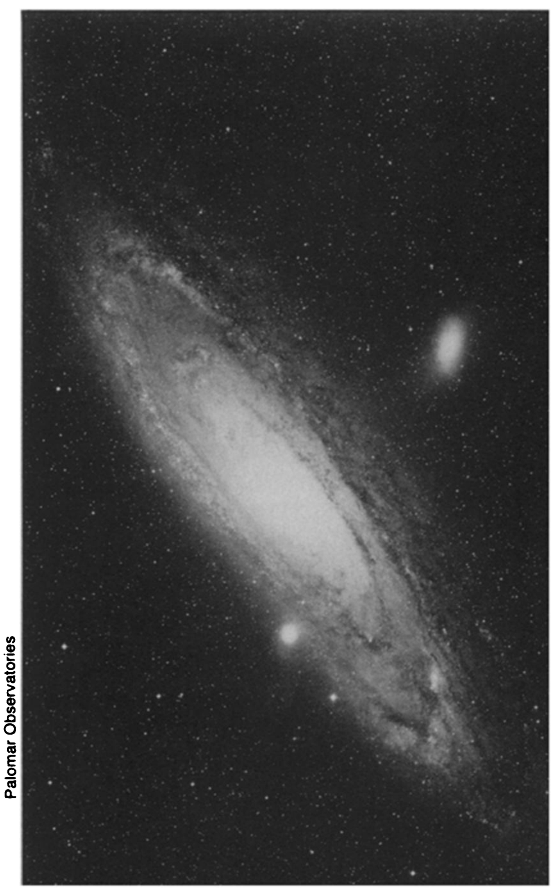
The enigma of the spiral nebulae and their vast distances had been solved by a 34-year-old. Born in Missouri, Hubble had already turned down a chance to become a professional boxer, had spent three years at Oxford as a Rhodes Scholar, had practiced law for one year, and then, deciding to "chuck law for astronomy," had earned his Ph.D. at the University of Chicago. After fighting in France during World War I, he went to the top of Mount Wilson in California, where he began taking his epoch-making measurements with the 100-inch telescope.

Gauging the universe was Hubble's goal, but the straightforward method, triangulation, worked only in the immediate neighborhood of the sun. The key that ultimately unlocked the vast distances for Hubble was the use of stars called Cepheid variables as a kind of cosmic yardstick.

Pushing the resolving power of the 100-inch telescope to its limit, he first discovered that he could just make out individual stars in Andromeda and two other nebulae. A few, moreover, looked like Cepheid variables. Through spectral analysis, he demonstrated that these stars were the same as Cepheid variables already observed in the Milky Way. This was a boon, for Cepheids pulsate in day- to week-long rhythms, and a relationship between their period and their real brightness had been discovered earlier in the century by Henrietta Leavitt of the Harvard College Observatory. From the faintness of Cepheids in the spiral nebulae, therefore, Hubble could and did calculate distances — and proved conclusively that these nebulae were star systems far beyond the Milky Way.

Their significance realized, Hubble began a galactic survey. In a short period he pinpointed more than 60,000 spiral and elliptical nebulae — each one a complete star system. In the total observable region of space, moreover, he estimated there were 100 million galaxies. Today we estimate close to 100 billion.

Old boundaries of the cosmos had been torn apart. Yet the discovery of independent galaxies was only the start of a mind-stretching voyage into space and time. By 1929, Hubble had estimated the distances of two dozen galaxies — a sample large enough to permit a search for general relationships. In that year, based on an analysis by Milton Humason of spectral redshift in galaxies, Hubble announced a spectacular conclusion: The "island universes" were rushing away from each other with a velocity that increased in proportion to the distance between them. The cosmos seemed to be exploding wildly outward, with each more-distant galaxy hurtling away at proportionately greater speed. And our galaxy was not at


Palomar Observatories

the center. For Hubble, this universe of galaxies was expanding uniformly, so that all its members were receding from one another.

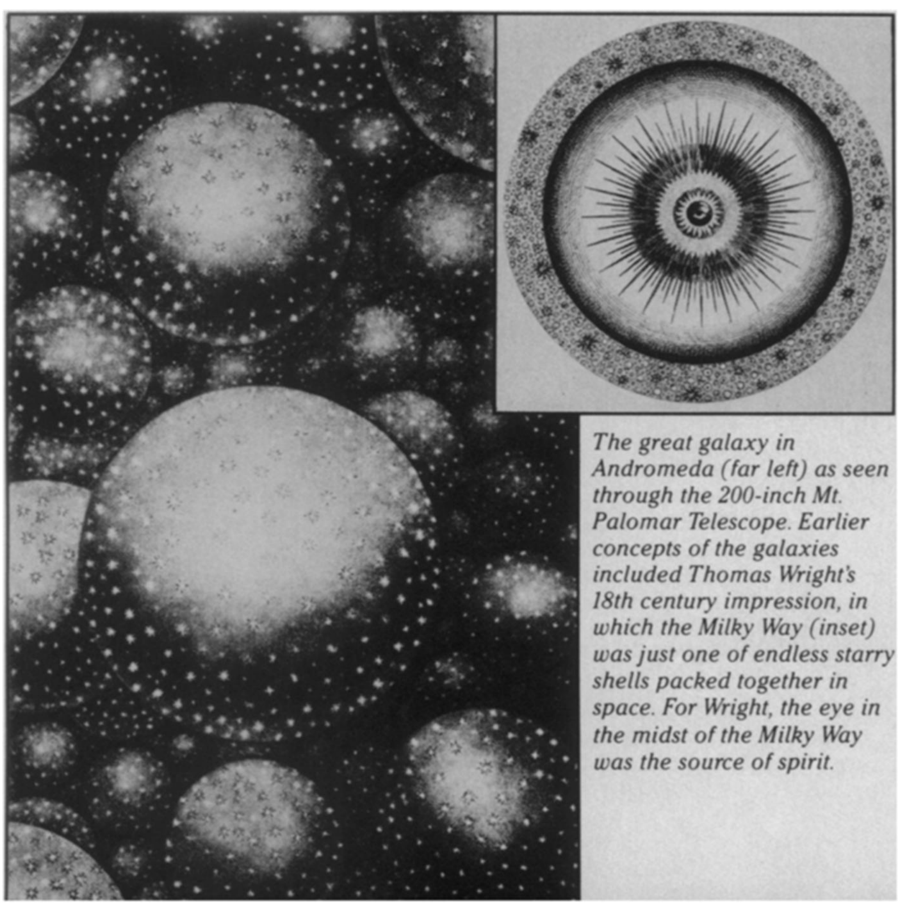
Not everyone agreed, and hot debate over Hubble's methods, assumptions and interpretations quickly ensued. Some astronomers felt that the redshift might be due to an in-flight change of the color of individual photons, but that suggestion raised more problems than it answered. The concept of expansion, moreover, became an integral part of relativity theory. It even provided a convenient answer to the paradox put forward by Heinrich Olbers more than a century ago: If stars (or galaxies) are distributed uniformly through space, and if space is infinite, why, Olbers asked, are we not blinded by their light? We would be, goes the explanation, except that we live in an expanding universe where light from distant sources is weakened, as shown by Hubble's redshift. In short, it didn't take long for the expanding universe to become later-day dogma.

The hiatus seems to be over, however, and speculation about the ultimate fate of the universe is again heating up, as evidenced by a large portion of this issue (see p. 141). Hubble's expanding universe is being theoretically accelerated, collapsed, or held in a steady state. But whether or not conflicting schools of thought settle the ultimate question, Hubble's original achievement still stands: He pushed us into a galactic perspective. Our galaxy is now but one among many.

It was an awesome discovery, yet a few sky watchers had speculated along the same lines hundreds of years earlier, even though they lacked Hubble's evidence. Immanuel Kant was one such seer. Another, more obscure visionary was Thomas Wright, an 18th century Englishman who raised himself from humble origins to the status of "gentleman" by surveying estates and teaching mathematics and physics to "noble ladies." His argument, published as *An Original Theory Or New Hypothesis of the Universe* in 1750, went something like this: Since stars were too far away for measuring instruments, they must be very bright. The brightest known object was the sun. Therefore, stars were assumed to be like the sun. Distances could then be estimated from their apparent faintness. In this way, Wright formulated an early conception of a stellar system isolated in space.

On an observational level, he accepted Galileo's conclusion that the Milky Way was a mass of unresolved starlight. But Galileo's conclusion, Wright noted, had also been held by Democritus, who believed the Milky Way to be composed of stars "long before astronomy reaped any benefit from the improved sciences of optics; and (who) saw, as we may say, through the eye of reason, full as far into infinity as the most able astronomers in more advantageous times have done since, even assisted with their best glasses." And Wright's speculations ranged far beyond the Milky Way. A single stellar system, isolated in the universe, did not satisfy his inquiring mind. He imagined other, similar systems (see drawing) and, as visible evidence of their existence, pointed to the mysterious clouds called nebulae.

It was an apt deduction, and Wright's vision found a sympathetic audience in Edwin Hubble, who saw it as an inspired application of "the uniformity of nature" principle or, in other words, the assumption that any large sample of the universe is much like any other. But there is more to Wright. After 20 years, he again published, only this time his work was not so inspired. His new universe was solid, except for a spherical cavity which held the earth. The stars were distant volcanoes, and the nebulous stars and comets were volcanic eruptions floating above the black ground of the sky. For Wright, the Milky Way had become a "vast chain of burning mountains forming a flood of fire."



The great galaxy in Andromeda (far left) as seen through the 200-inch Mt. Palomar Telescope. Earlier concepts of the galaxies included Thomas Wright's 18th century impression, in which the Milky Way (inset) was just one of endless starry shells packed together in space. For Wright, the eye in the midst of the Milky Way was the source of spirit.

If not always correct, at least Wright's theorizing showed spunk. The same can not be said of Charles Messier, a Frenchman who published in 1781 a list of 103 nebulous objects and clusters he had come across in the course of comet hunting. Unlike Wright, Messier totally refrained from speculation on the nature of the nebulae. He simply listed positions and gave brief descriptions so an observer of moderate experience could make an identification. Messier did not fathom what he saw, but his lists became the starting point for later searches that opened up the Milky Way and that led astronomers to external galaxies. To this day, astronomers still refer to the Andromeda Nebula, for instance, as M31, in recognition of Messier's pioneering, if somewhat myopic, work.

Others saw more clearly. In 1852 Stephen Alexander, a professor of mathematics and astronomy at the College of New Jersey, later Princeton University, suggested that the Milky Way was one among a multitude of spiral nebulae. His discussion, however, was rather abstract and vague, and did not attract much attention. There was, moreover, nothing that could be done to prove or disprove Alexander's theory. The crucial observations just weren't available.

It took Hubble and the huge telescopes of Mount Wilson to plumb the vast depths of the universe and prove the reality of separate star systems. Hubble's work, however, was not just an immense step into space, it was an incredible trip through time as well. Assume that Hubble's redshift assumptions are correct, and that all the galaxies around us are moving apart from us and from one another at enormous speeds. If we then retrace the motions of the outward-moving galaxies backward in time, we find that they all come together roughly 20 billion years ago.

Packed into a tight mass, all this matter seethed at temperatures of many trillions of degrees. The dazzling brilliance of the radiation in this dense, hot universe must have been beyond description. The picture suggests the explosion of a cosmic bomb—and the instant at which the bomb exploded marked the birth of the universe. □