THE WOMAN WHO SPINS THE STARS

Something in the universe just doesn't add up, says Vera Rubin. And after a lifetime of careful measurements, she's got the numbers to prove it.

BY MARCIA BARTUSIAK

In 1938, when Vera Cooper was ten years old, her family moved from Philadelphia to Washington, D.C. In her new bedroom she slept beneath a window that faced north. At night, as the Earth turned and Vera struggled to stay awake, she would watch the slow procession of the constellations around the North Star; if a meteor blazed down from the heavens, she would memorize its trail. "Don't spend all night hanging out the window," her mother would say. But young Vera was hooked.

Vera Cooper has long since added the surname Rubin to her own, and the hair that was long and brown is now gray-white and cut comfortably short. But she still lives in Washington, D.C., and she is still fascinated by celestial motions. Only now when she ponders them, she travels to mountaintops in Arizona, California, and Chile and looks through the electronic eyes of the world's largest telescopes.

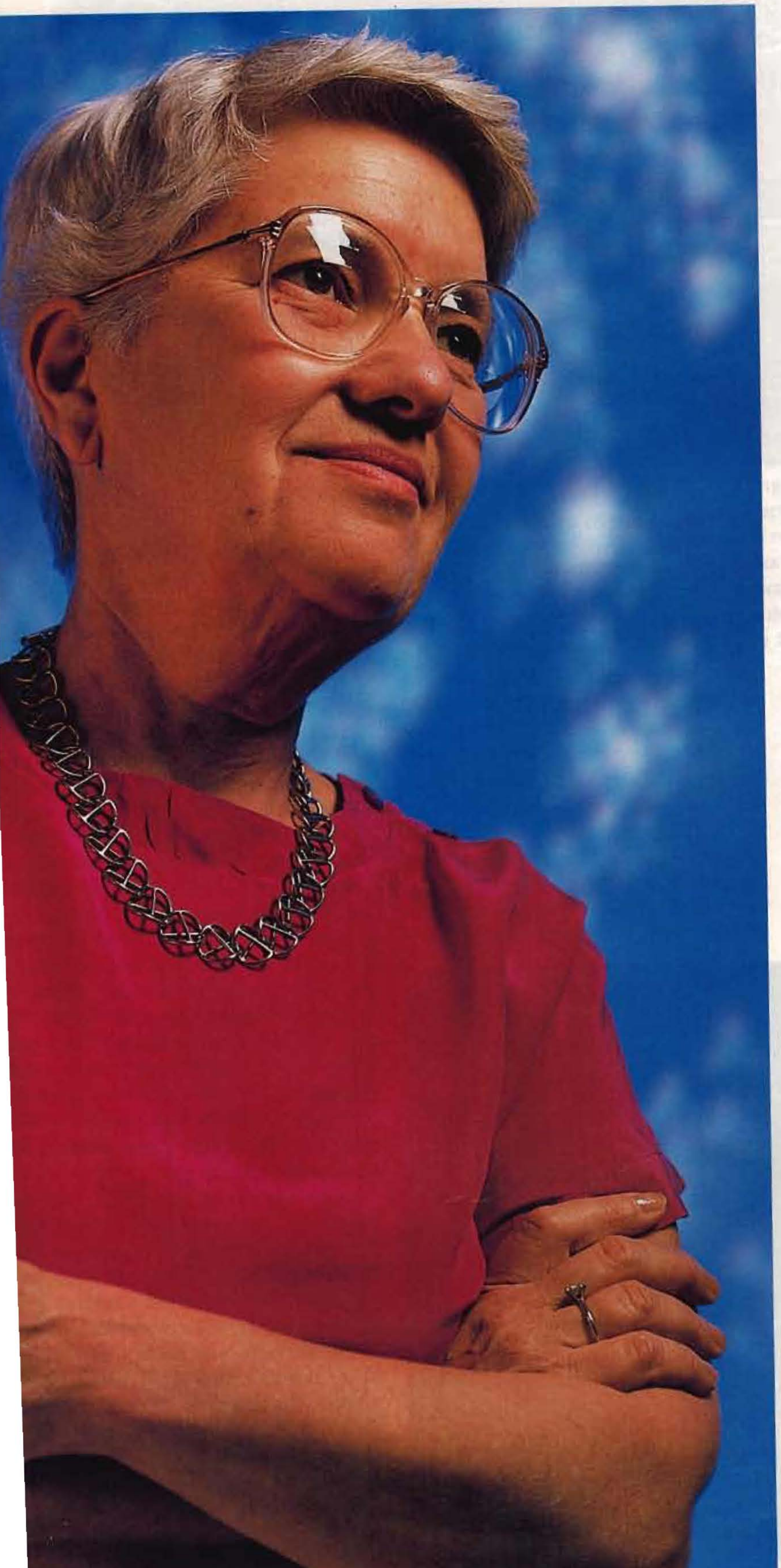
Among her fellow astronomers Rubin is known as an expert observer of the night sky, one of the best. Her reputation derives from the project she has doggedly pursued throughout most of her career: measuring how fast spiral galaxies are spinning, from their luminous cores out to the faint wisps of light at their fringes. Such a task may sound tedious; even her colleagues thought so when she started the project, 20 years and 200 galaxies ago. But with her painstaking measurements Rubin has learned something important about galaxies: they spin so fast they ought to fly apart. Apparently they remain intact only because they are embedded in vast spheres of matter whose gravity keeps the stars in check. We cannot see this matter—it is dark to all our detectors. But it seems to make up at least 90 percent of the mass of the universe.

Largely because of Rubin's work, dark matter has become *the* buzzword in astronomy. Observers are desperate to find some way of seeing it; theorists are desperate to find an explanation of what it is—swarms of unknown elementary particles, for instance, or hidden armadas of Jupiterlike planets. Yet Rubin never intended to stir up such ferment, let alone change the way we see the universe. When she began her career, all she wanted was to keep looking at the stars.

In Rubin's basement office there is a giant blowup of the Andromeda galaxy on the ceiling, a print of Van Gogh's *Starry Night* on the wall, and, on this particular day, cardboard boxes all over the floor. Rubin and many of her colleagues at the Carnegie Institution of Washington's Department of Terrestrial Magnetism (a name that dates from the organization's original mission of mapping Earth's magnetic field) are moving to a newly constructed building next door. The department's lush grounds are a chaos of trucks; the library has been closed; and the computer system is about to be shut down for weeks. Some of the staff have escaped by going on vacation, but Rubin—just back from the Kitt Peak National Observatory, where she

PHOTOGRAPH BY KATHERINE LAMBERT

Vera Rubin is known for her kindness. She is also known for having made the observations that all but cinched the existence of a universe full of dark matter.



had four nights of the clearest observations of her life—is staying on. "Each hour is precious right now," she says. "I won't be able to see my images on the computer for a month." She is warm and cordial nevertheless. Rubin always gives full attention to the task at hand, whether it is computing, observing, or reflecting on her career.

She is a researcher who dislikes controversy—so much so that she often tries to escape it. Yet, somehow, she has always picked problems that have thrown her into the thick of it. Her career has been marked with a series of professional setbacks that might have proved insurmountable to others.

Certainly her path was not laid out for her. Rubin remembers a high school physics teacher telling her, "You'll do all right so long as you stay away from science." Fortunately her father, an electrical engineer, encouraged her, helping Rubin build her first telescope when she was 14 years old and taking her to amateur astronomy meetings in Washington.

At one point Rubin contemplated going to Swarthmore College in Pennsylvania to major in astronomy. A Swarthmore admissions officer suggested she pursue the more ladylike career of painting astronomical subjects. "That became a standard joke in my family for many years," she says, laughing. "Whenever anything went wrong for me at work, someone would say, 'Have you ever thought of a career in which you paint. . . .' "

Turned down by Swarthmore, Rubin entered Vassar at the age of 17 and graduated three years later with a bachelor's degree in astronomy. She wanted nothing more than to continue her work at Princeton, then, as now, a prestigious astrophysics center. Enthusiastic and naive, she wrote away for a catalog of its graduate school. She never received the catalog; Princeton did not accept women into its graduate astrophysics program until 1971.

She ended up going to Cornell, where her husband, Robert Rubin, was a graduate student in physical chemistry. At Cornell she was doubly the outsider: she was a woman, and she was in what was then a mediocre astronomy department consisting of only two faculty members. But since her course work was largely in physics, she was in the right place at the right time:

Hans Bethe, who would win a Nobel Prize for unraveling the fusion reactions that power the sun, taught her quantum mechanics; and she learned quantum electrodynamics from the flamboyant Richard Feynman.

By the time Rubin arrived at Cornell, astronomers had known for two decades that the universe was expanding. They had observed that light waves from distant galaxies are stretched, or shifted toward the red end of the spectrum, and had concluded that a galaxy's redshift is a measure of how fast it is moving away from us as it is swept along by expanding space-time. The idea that the expansion had started with a Big Bang was just gaining currency.

For her master's thesis Rubin decided to ask whether the galaxies were swinging around the cosmos as well as ballooning outward. George Gamow, an early proponent of the Big Bang theory, had speculated that galaxies might rotate around the universe the way stars swirl around a galaxy, but he was pretty much alone in this view. It was thus a daring question for Rubin to pursue, especially considering the paucity of data she had to work with. Galactic velocities were extremely difficult to measure, and at the time, out of billions of galaxies, astronomers had managed to obtain only 109 redshifts. Nevertheless, upon analyzing these redshifts, Rubin concluded that the galaxies did display some extra, sideways motion apart from the outward motion due to cosmic expansion.

"My first paper got an enormous amount of publicity, almost all negative. But at least, from then on, astronomers knew who I was."

In 1950, three weeks after the birth of her first child, she announced her findings at the eighty-fourth meeting of the American Astronomical Society, held that year in Haverford, Pennsylvania. The report, her professional debut, was one of 50 papers presented. (Around 800 would be given at such a meeting today.) No one believed the unknown 22-year-old; her data seemed much too scanty. Her paper had almost been banned from the conference, and it was later rejected by every top journal. "It got an enormous amount of publicity, almost all negative," recalls Rubin. "But at least, from then on, astronomers knew who I was."

The first galaxy Rubin studied in detail was nearby Andromeda.

In hindsight, she suspects her data were too poor to justify her conclusion; but a measure of vindication was to come decades later.

Soon after the conference she moved back to Washington, where her husband began a new job, and she, with her growing family responsibilities, began to feel adrift. "I actually cried every time the *Astrophysical Journal* came into the house," she says. "I knew that getting a master's degree didn't make me an astronomer, but nothing in my education had taught me that one year after Cornell my husband would be out doing his science and I would be home changing diapers."

The frustrations led her to Georgetown, the only school in the area with a Ph.D. program in astronomy. It was a family enterprise. For nearly two years, while Rubin's parents watched the children, her husband drove her to the university and ate his supper in the car while she attended her nighttime classes.

Rubin's pioneering doctoral thesis tackled the distribution of galaxies. Was there a pattern to their positions in the sky? she asked. Or were they arranged more or less randomly? For months she slogged through her calculations on a desktop calculator; today, a computer could complete the analysis in a few hours. Her result—that there was a noticeable clumpiness in the spread of galaxies—caused hardly a ripple in 1954. In fact, the topic was not seriously studied until 15 years later. Again she had jumped the gun, a penchant she attributes as much to her academic isolation as to her curiosity. She wasn't constrained by the party line that pervaded the more prestigious universities—in this case, the dogma that galaxies ought to be smoothly distributed.

After receiving her Ph.D., Rubin taught and did research at Georgetown. Professionally, her life throughout the 1950s was rather uneventful, but, as evidenced by four short lines in her curriculum vitae, she's enormously proud of the work she was doing then. Ahead of her awards, ahead of her distinguished degrees, she lists these accomplishments: David (1950), Ph.D. geology; Judith (1952), Ph.D. cosmic-ray physics; Karl (1956), Ph.D. mathematics; and Allan (1960), Ph.D. geology.

Not until 1963 did Rubin's astronomical career finally get the spark it needed. She and her husband spent a year at the

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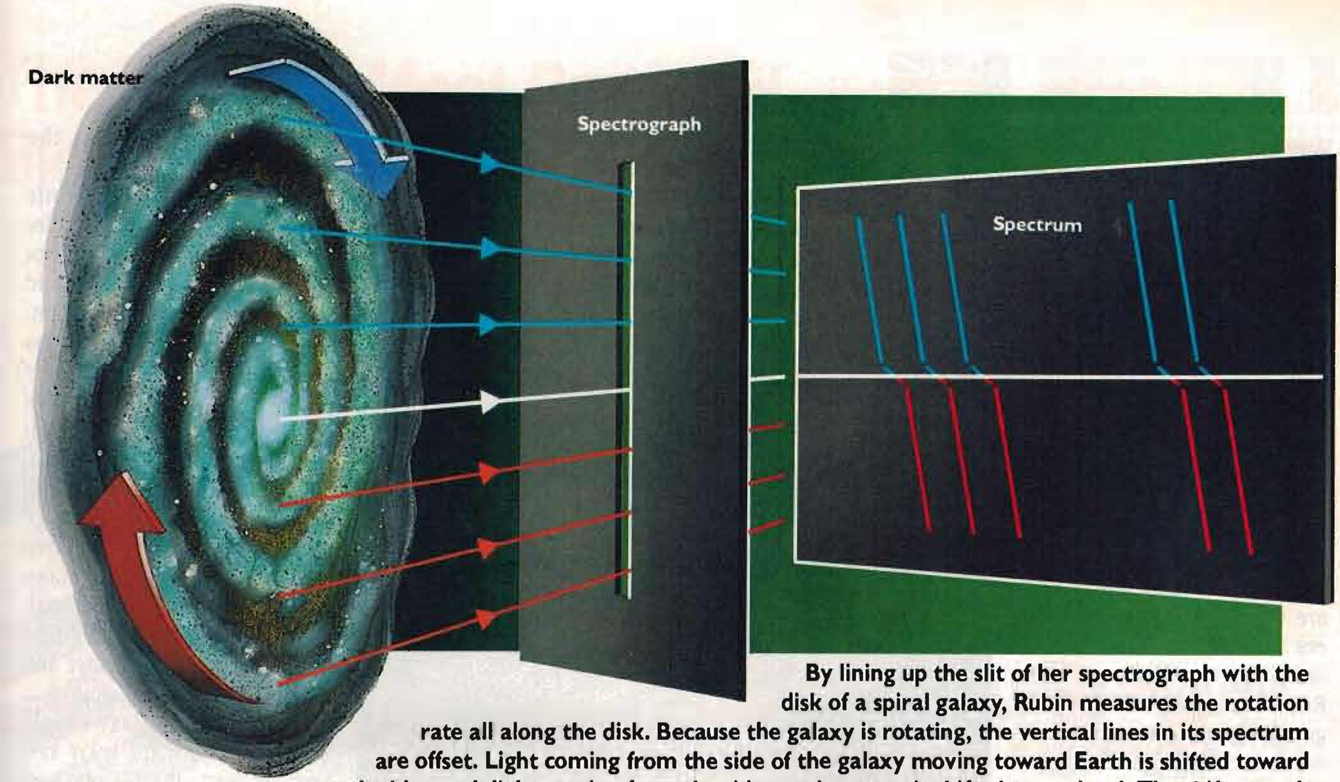

By lining up the slit of her spectrograph with the disk of a spiral galaxy, Rubin measures the rotation rate all along the disk. Because the galaxy is rotating, the vertical lines in its spectrum are offset. Light coming from the side of the galaxy moving toward Earth is shifted toward the blue end; light coming from the side moving away is shifted toward red. The shift at each point on a spectral line indicates the rotation velocity at the corresponding point on the galactic disk. The case for dark matter is that the velocity doesn't *decrease* toward the disk's edge, as it should if the bulk of the galaxy's mass is in the center.

University of California at San Diego, where she worked with Margaret and Geoffrey Burbidge, the husband-and-wife team who had recently helped establish that most chemical elements are made in stars. "That was probably the most influential year in my life," says Rubin. "In my mind I had at last become an astronomer, for the Burbidges were actually interested in my ideas."

At the same time, Rubin started her career as a professional observer—at Kitt Peak in Arizona, which had recently opened. Soon after returning to Washington, she went over to the Department of Terrestrial Magnetism, a place she had visited and fallen in love with years earlier. She asked for a job and got it. She was 36.

The DTM, as it is called, is an unusual organization. Its staff is small, only a couple dozen researchers in all, and the atmosphere is familylike. The daily staff lunches, which each person fixes for the group on a rotating basis, are an occasion for gossip as well as scientific chats. The DTM is known for the freedom it grants its researchers—in particular the freedom from the publish-or-perish edict that reigns in academia.

Rubin has thrived in this atmosphere, and she has cultivated it herself. "DTM was the happiest and most harmonious place I've ever done scientific work," says David Burstein, who worked with Rubin as a postdoc from 1977 to 1979. "Vera established an atmosphere where it was a joy to do astronomy. Differences were debated, not argued. Even when Vera and I disagreed, she was never vitriolic, so I never took it personally. And she often told me, 'You don't do astronomy for money or publicity; you do it for your own satisfaction.' "

One of Rubin's chief satisfactions at the DTM has been collaborating with W. Kent Ford for the past 25 years. Ford is a physicist and designer of astronomical instruments; when Rubin arrived at the DTM, he had recently helped perfect an image tube that, when placed in front of a photographic plate, made it possible to collect light ten times faster. His technical skills complement Rubin's analytic ones almost perfectly. "Vera is a remarkable, wonderful person," says Ford. "However, we do have one intense disagreement: we both think we're more skilled in guiding the telescope. We've bumped heads trying to get to the eyepiece first."

When Rubin and Ford first started working together, they dabbled in quasars: mysterious blue specks that lie at the edge of the visible universe and are thought to be the brilliant cores of young galaxies. In the mid-1960s quasars had just been discovered, and they were the hottest topic around. Rubin, however, came to dislike the hurried pace that goes with hot topics. "People were constantly calling me asking whether I had obtained a certain redshift before I was sure whether the data were good," she complains.

In the early 1970s she and Ford returned to the question asked by her master's thesis: Do galaxies just go along for the ride as the universe flies outward, or do they move around on their own as well? Again, she found some extra motion, and again her findings were overwhelmingly rejected. Bitter arguments about the "Rubin-Ford effect" broke out at conferences; noted astronomers wrote Rubin urging her to quit the research. "People were very . . . outspoken," she says after a diplomatic pause. "There was a belief that the expansion of the universe was quiet and smooth, and that there were no large individual or large-scale motions superimposed upon that expansion. We interpreted what we observed as a large motion of our own galaxy. I guess that was not easy for some people to believe."

Some astronomers still contend Rubin's results were questionable. But her basic idea, if not her detailed results, has been vindicated. The cosmic sea, it now appears, is stirred by strong, local currents that have nothing to do with the general expansion. The Milky

Way and all the galaxies in a vast region around us are being gravitationally drawn toward a distant concentration of galaxies called the Great Attractor. But 15 years ago such large-scale streaming went against everyone's expectations—and everyone let Rubin know it. Distressed by the reception her work was getting, Rubin simply dropped it. She turned her attention to a problem that seemed far less controversial: the rotation of spiral galaxies.

Rubin hoped to learn, with little fanfare, why spirals vary. There are dim ones, bright ones, spirals whose starry arms are tightly wrapped, and others with their arms splayed wide open. A galaxy's spin, Rubin guessed, must surely go a long way toward explaining its structure. The Burbidges had already looked at some galactic centers, but Rubin was curious about what was happening farther out in the spiral arms. So while the most famous of her colleagues were tracking down pulsars and quasars, Rubin quietly and determinedly started to measure galactic rotation rates. The existing data were sparse, and for good reason. In the early part of this century it took dozens of hours to make the first crude estimates of the rotation of Andromeda, the closest spiral galaxy to the Milky Way and by far the brightest from our vantage point. But with the image tube Ford had perfected, Rubin and Ford could now record a spectrum in just 2 or 3 hours rather than 30.

The first galaxy they studied was Andromeda. Andromeda's spiral disk is slightly inclined toward Earth, so its rotation carries the stars and gas on one side of the disk toward Earth and those on the other side away from it. As a result, the wavelengths of light emitted by material approaching Earth get a bit shorter—that is, they become bluer; for material moving away, the light waves lengthen, or get redder. By measuring these shifts, Rubin and Ford could measure the rotational velocity of the galaxy at various distances from its center, all along the disk.

Individual stars in other galaxies, even one as close as Andromeda, are generally too faint for their spectra to be recorded easily, so Rubin and Ford focused on clouds of gas lit up by hot stars—but even that operation was tricky. "The knots of gas are so faint that they cannot be seen directly through the telescope," explains Rubin. "We had to set the slit of the spectrograph on a section of the sky where nothing was visible. It was a great act of faith—setting the slit, exposing the photographic plate for two or more hours, and then developing the plate. We went for every photon we could get." All this had to be done with extreme care; a speck of dust on the wrong spot could have ruined a night's work at the telescope. Today Rubin and Ford, like many other astronomers, have switched to superefficient electronic detectors that display the final images on computer monitors, making the whole process considerably easier.

NGC 5676 is one of 200 galaxies Rubin studied. The vertical line in its spectrum is from its bright center. The strong horizontal line is that of hydrogen, shifted toward blue on the left and toward red on the right.

When Rubin analyzed the subtle shifts in Andromeda's spectral lines under a microscope, she found that it did not rotate the way she or anyone else would have expected. Most spiral galaxies, including Andromeda, have a luminous central bulge, composed of densely packed stars. The spiral disk that surrounds the bulge, on the other hand, is very thin, and its brightness falls off steadily toward the edge. Astronomers had generally assumed that the mass of a galaxy would follow the same pattern as the light: it would be concentrated in the center and decrease toward the rim.

That meant a galaxy should behave like a giant solar system. Almost all the mass of our solar system is tied up in the sun, so it is the gravitational pull of the sun that determines the speed of the planets. According to Newton's law, that pull decreases with the square of distance from the sun. Thus the inner planets, such as Venus and Earth, practically race around the sun, while the planets farther out, where the sun's gravity is weaker, proceed at a much slower pace. The stars and gas at the edge of a spiral disk were expected to behave in the same way, orbiting the massive core much slower than stars farther in.

Andromeda deviated from this expectation in a surprising way. "The rotational velocity of the individual gas clouds remained high at large distances from the center of the galaxy," recalls Rubin. "But we weren't smart enough to understand it. We didn't think we were finding a property of the universe—we thought that Andromeda was a peculiar galaxy, and that the next one would be more like what we expected. So we didn't make a great thing of it."

The importance of the finding became clear only when Rubin, Ford, and a team of Carnegie postdocs began to examine the spins of other spiral galaxies, picking ones that, like Andromeda, are inclined toward Earth. In galaxy after galaxy, they saw that stars and gas at a disk's edge travel just as fast as matter closer to the center. When they

PHOTOGRAPHS: GALAXY BY JAMES D. WRAY; SPECTRUM COURTESY VERA RUBIN plotted rotational velocity against distance from the center—a graph called the rotation curve—they got the same pattern all the time: moving out from the center, the velocity increased rapidly to a plateau, which it sustained all the way to the visible edge of the disk.

If the planets in our solar system adhered to this pattern, the outer ones would have careered off into interstellar space long ago. Since galaxies do not seem to be shedding stars the way a sprinkler sheds water, however, something must be holding the stars in. That something has to be gravity, no other force being powerful enough on a galactic scale. And where there's gravity, there's mass. Rubin realized that a huge reservoir of extra material, invisible to her telescope, must be tucked away somewhere in each galaxy.

Rubin was not the first to suspect that there was more in the heavens than meets the eye. As early as the 1930s, astronomers Fritz Zwicky and Sinclair Smith had noticed that galaxies in clusters moved around far too fast, and they suggested that some additional matter pervaded the cluster to act as a gravitational glue. In the early 1970s astronomers observed radio-emitting hydrogen gas at the edge of a few spiral galaxies and found, as Rubin was to find later for visible matter, that the gas on the edge moves just as fast as gas farther in. These were isolated observations, however, and in general they were either attributed to instrument error or simply ignored.

Rubin holds a photo of herself with the telescope she used at Vassar.

Rubin's arsenal of measurements—since 1978, the Carnegie group has analyzed 200 galaxies—took dark matter off the back burner. "I think we learn with our eyes," she says, "and the visual impression of seeing the rotation curves was so striking that it was relatively easy for people to accept." What has come to be accepted, thanks to her, is an entirely new picture of a galaxy: one in which the visible galaxy is but a luminous smudge immersed in a sphere of dark, unknown matter that is five to ten times the mass of the glowing spiral.

On the question of what the dark matter might be, there are two vocally competing camps. Astronomers, impressed mostly by observations, are fond of saying that the "dark matter could be cold planets, dead stars, bricks, or baseball bats," as Rubin puts it—but that there is no reason to believe in something new and exotic. On the other hand, something new and exotic is precisely what cosmologists want, for their own, entirely theoretical reasons. According to the current fashion in cosmology, a superaccelerated burst of spacetime inflation at the moment of the universe's birth generated a flood of exotic (yet-to-be-discovered) particles that far outweigh the ordinary, visible stuff of people and planets. Indeed, the cosmologists' dark matter ends up weighing 100 times as much as all the visible matter in the universe—10 times more than Rubin needs to keep her spiral galaxies from flying apart.

Until someone actually finds the dark matter, the debate between these two camps is not likely to subside. Meanwhile, the woman who helped start it all, the same woman who could not get her master's thesis published, was elected to the National Academy of Sciences in 1981. She is one of only 75 women among the 3,508 researchers elected to the academy since it was chartered in 1863. But if that impresses her, she doesn't let on. "Fame is fleeting," says Rubin. "My numbers mean more to me than my name. If astronomers are still using my data years from now, that's my greatest compliment."

Rubin is still watching galaxies—although with so many astronomers chasing so few telescopes, she can manage only about eight nights a year on the mountain—and she is still generating data. An early bird, she often gets to the office by 7:00. "What I would call a good week would be one in which I could spend the entire day on science—analyzing data and writing papers," she says. But that is not a typical week for Rubin. A lot of her time is spent meeting with visitors, giving professional talks, and working for such groups as the National Academy's Committee on Human Rights. Science education is also a special concern; she has twice volunteered to teach an astronomy course at her children's high school, and she serves on the advisory board of a science program for inner-city youth.

Indeed, in Rubin's eyes the chief significance of her dark-matter discovery is the legacy it leaves to future generations. "In a very real sense, astronomy begins anew," she said recently in a public lecture. "The joy and fun of understanding the universe we bequeath to our grandchildren—and to their grandchildren. With over ninety percent of the matter in the universe still to play with, even the sky will not be the limit."

So keen is Rubin on recruiting young people, especially girls, to explore the dark-matter universe that she has written a children's book, for which she is now seeking a publisher. It's called *My Grandmother Is an Astronomer.* ☐

PHOTOGRAPH BY KATHERINE LAMBERT

Ten years ago, in the first issue of DISCOVER, contributing editor Marcia Bartusiak wrote about Mount St. Helens.