Vera C. Rubin

1928–2016

BIOGRAPHICAL *Memoirs*

A Biographical Memoir by
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NATIONAL ACADEMY OF SCIENCES

VERA COOPER **RUBIN**

July 23, 1928–December 25, 2016

Elected to the NAS, 1981

By Neta A. Bahcall

Vera Cooper Rubin, a pioneering astronomer, revolutionized our understanding of the universe through her observations of the motions of stars in galaxies, which revealed the existence of dark matter in the universe. A tireless and dedicated observational astronomer, inspiring leader, devoted champion of women in science, beloved mentor to generations of astronomers—Vera was a close colleague and friend to many of us. Her careful observations of the motions of stars in spiral galaxies revealed that their rotation speed around the galactic center was faster than expected—their speed did not decrease in the far reaches of the galaxies as would be expected from Newton's gravity. The so-called "rotation-curves" of galaxies remained flat, at constant velocity, even at large radii from the center of galaxies, rather than declining with radius due to the expected decrease in gravitational pull. These flat rotation-curves—a hallmark of Vera's pioneering discovery with her colleague Kent Ford—implied the existence of additional matter in galaxies, on top of the mass in stars, otherwise these fast-moving stars would fly out of the galaxy. These results provided the clearest evidence for the existence of dark matter in the universe and revealed that galaxies are embedded in large halos of dark matter. The nature of the dark matter—the exotic particles that make up this matter—is still a mystery. Many experiments have sought to find dark matter particles, but without success. Hopefully, a detection will be made soon. We now know that most of the mass in the universe, 85 percent, is made up of this exotic dark matter; only about 15 percent of the cosmic mass is normal atomic matter. The existence of dark matter affects the evolution of our entire universe and the formation of galaxies and other structures.

A lifelong lover of the cosmos, Vera advanced slowly but persistently at a time when women were not welcome in science or academia. With incredible perseverance, dedication, hard work, and an insatiable love of astronomy, Vera overcame many of these early obstacles and rose to success, recognition, and admiration. Vera remained humble, kind, warm, supportive, and caring. She was loved and admired by everyone. Vera was a close colleague and friend of mine for many years; I could not have wished for a better friend, more caring colleague, inspiring role-model, and kinder human being than Vera. She was a "mensch."

The Early Days

Vera Florence Cooper was born in Philadelphia on July 23, 1928. Her parents were Jewish immigrants from Eastern Europe who encouraged Vera and her sister Ruth to pursue their education and apply themselves towards any direction they were interested in. Vera became a scientist; Ruth became a judge. Vera's interest in astronomy started at a young age. Her father helped her build a cardboard telescope that she used to observe the stars. She checked out library books on astronomy and the night sky and read them with delight. She was fascinated by the night sky; she watched the Moon from her bedroom window and wondered why it was moving every night. She watched the stars and wondered what they were made of. "There was just nothing as interesting in my life as watching the stars every night," she said. Her curiosity was endless.

The Cooper family moved to Washington, D.C., when Vera was 10. She went to Vassar College in Poughkeepsie, New York, at the time an all-women's college, because the first professional female astronomer in the United States, Maria Mitchell, had taught there in 1865–88 and because Vassar had a modern small telescope available to students. Vera was excited about the opportunity to use it. Telescopes were her love. When Vera applied to college, an interviewer dismissed her interest in studying astronomy; "why don't you consider a career painting astronomical objects?" he suggested. Luckily, Vera was not deterred by the negative comments, nor by many similar ones that followed in the years to come. I wonder what this adviser would think today about his misguided "advice." Vera graduated from Vassar in 1948 as the sole astronomy student in her class. She also married her husband, Robert Rubin, that year. Bob was a mathematical physicist and chemist (and an outstanding tennis player) who supported Vera's career with enthusiasm and devotion throughout. Bob and Vera were married for sixty years until Bob's passing in 2008. They were a loving and supportive couple, best friends, a wonderful scientific match, and devoted parents to four delightful children—all scientists.

After graduation, Vera entered graduate school at Cornell University, where her husband Bob was doing his graduate work. Vera received her master's degree from Cornell, working on the motion of galaxies in the universe on large scales. The results were unexpected—and controversial. They suggested large-scale motions and implied a possible rotation of the universe. We now understand these results as local gravitational effects combined with observational uncertainties. I quote below Vera's own description of her experience at that time,[1] after she gave her first talk at an American Astronomical Society (AAS) meeting in 1950 at which she presented these results. This illustrates, in Vera's own words, her early experience as well as her personality:

> *For my Masters thesis, I examined the velocity distribution of the galaxies with published velocities. At that time, the number of such galaxies was only 108. Dr. Stahr was my advisor. After I gave the Chairman a copy of my completed thesis, he called me into his office and said (as closely as I can now quote), "This is very interesting and you should give a talk at the December 1950 Haverford AAS meeting. But you will have your new baby, and you are not an AAS member, so I could give the talk but it would have to be in my name." Immediately I replied, "No. I can go." We had no car. My parents drove from Washington D.C. to Ithaca, then crossed the snowy New York hills with Bob, me, and their first grandchild, "thereby aging 20 years," my father later insisted. The next morning, Pete drove Bob and me to the AAS Haverford meeting. I gave my memorized 10-minute talk, acceptably I thought. Then one by one many angry sounding men got up to tell me why I could not do "that." All except a little man with a squeaky voice (later identified as Martin Schwarzschild), who said what you say to a young student: "This is very interesting, and when there are more data, we will know more." Following this confusion, a coffee break was called. We left shortly afterward, for I was anxious to see how the baby was doing away from his mother for the first time. I was told that my first words when I entered the house were, "Was he happy?" The next day,* The Washington Post *front page noted, incorrectly, "Young Mother Finds Center of Creation" or something like that. Fifty years later, friends made a fake front page: "Old Grandmother Gets Medal of Science." They were certain that I would remember the original. I did.*

Following Cornell, Vera and Bob moved back to Washington, D.C., where Vera continued graduate school at Georgetown University and obtained her Ph.D. in astronomy in 1954. Astronomy graduate courses at Georgetown were offered at night at the time. Vera had a baby at home and was pregnant with her second child. Bob would drive her to Georgetown a couple of nights a week for her classes while Vera's mother stayed with the baby at home. Bob would drop Vera off, sit in the car to eat his dinner, and wait until Vera finished her classes, then drive them both back home. That's how it went for several years. For her Ph.D., Vera worked under the supervision of renowned physicist George Gamow. Her thesis explored the distribution of galaxies in the universe, using the then-available data. The results showed that the distribution of galaxies was clumped rather than being uniformly distributed in space, a surprising and important result that was ignored for many years. Years later, similar studies were independently carried out using significantly more extensive data. The clumpy distribution of galaxies was then recognized as a fundamental fact of our universe.

After completing her Ph.D., Vera remained at Georgetown for the next ten years, serving as a lecturer teaching astronomy courses and as a research assistant. Forty-three years later, in 1997, Vera was awarded an honorary degree from Georgetown University.

Dark Matter and the Carnegie Years

In 1965, Vera decided that she wanted to do more observations using telescopes, which she loved. She approached her colleague Bernard Burke, then at Carnegie's Department of Terrestrial Magnetism (DTM) in Washington DC, and asked for a job. Shortly thereafter, she joined DTM and began the lifelong observational trajectory that led her to the important discovery of dark matter in galaxies. Vera remained at DTM for her entire career. She loved DTM and thrived there. It was a perfect fit for both Vera and the department. In its peaceful environment, surrounded by wonderful colleagues and having the academic freedom to do what she loved best, Vera carried out her ground-breaking research about galaxy rotation and dark matter and meticulously mentored generations of young scientists studying galaxy dynamics.

Vera's pivotal observational work in the late 1960s and 1970s established that the orbital speeds of stars in the outer parts of galaxies remain constant to large distances—known as "flat rotation curves"—rather than declining as expected according to Newton's law. Just as planetary motion speeds decline in the outer parts of our Solar system—Jupiter and Neptune rotate more slowly around the Sun than does the Earth due to their larger distance and weaker gravitational pull by the Sun—so do stars farther away from galaxy centers rotate slower than the stars closer in. The observed excess speed of the distant stars requires excess mass beyond what exists in stars and gas. Without such excess mass, these fast-moving stars would fly out of the galaxy. Vera's observations provided crucial and convincing evidence for the existence of this excess "dark matter." It is named dark matter because it is dark, it does not shine. We also know, from other observations, that this dark matter is not the normal atomic matter that we are familiar with; it has to be a new type of particle(s), yet undiscovered. The suggestion of the existence of dark matter in the universe was first made by the famous astronomer Fritz Zwicky in 1933 based, similarly, on large velocities observed in clusters of galaxies, which implied large amounts of dark matter. Though Zwicky was correct, his suggestion was controversial at the time and took nearly forty years to become accepted. Vera's flat rotation curves in the 1970s provided the additional evidence for the existence of dark matter; it implied that galaxies themselves are embedded in large dark matter halos. We now know that these halos contain most of the mass in the universe.

Vera's observations were carried out in close collaboration with her DTM colleague Kent Ford, who built the uniquely sophisticated spectrograph that enabled these very precise measurements. Their first results, in 1970,[2] were for our nearby Andromeda galaxy (See Figure 1).

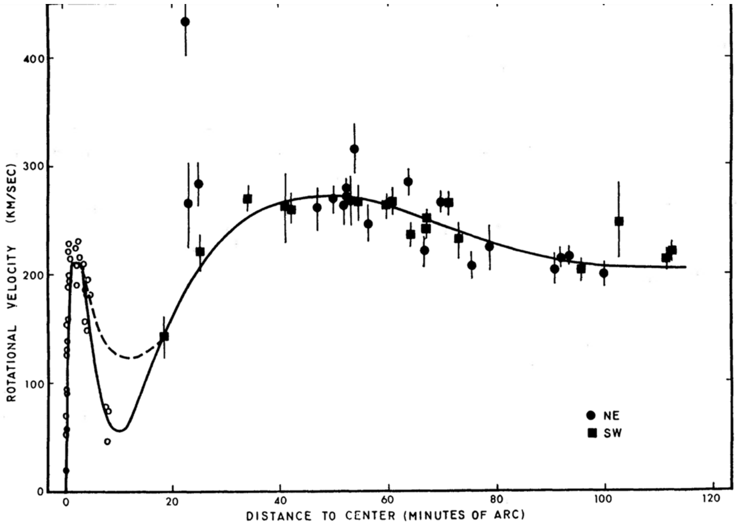

Fig. 1.—Rotational velocities for OB associations in M31, as a function of distance from the center. *Solid curve*, adopted rotation curve based on the velocities shown in Fig. 4. For $R \leq 12'$, curve is fifth-order polynomial; for $R > 12'$, curve is fourth-order polynomial required to remain approximately flat near $R = 120'$. Dashed curve near $R = 10'$ is a second rotation curve with higher inner minimum.

At that time, rotation curves were also being observed with radio telescopes, tracing the rotation of the neutral hydrogen gas disks that surround spiral galaxies; these observations, carried out by Morton Roberts[3,4] and others using the 21-centimeter line of neutral hydrogen, found similar results. Vera and Ford's observations of the stellar rotations, using optical telescopes, were less prone to interpretation of gas dynamics. Both sets of observations ultimately revealed the striking constant, non-declining, rotation speeds of galaxies, thus the need for dark matter. Rubin's and Ford's observations of a large sample of galaxies in 1978[5] (see Figure 2), all showing the same remarkable flat rotation at large

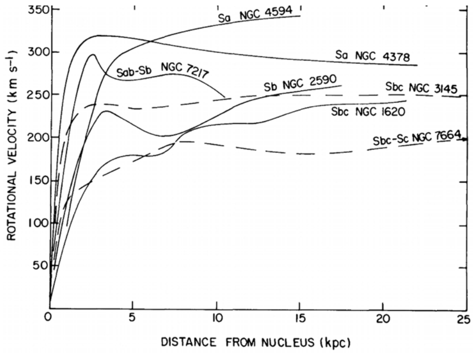

FIG. 2 —Rotational velocities for seven galaxies, as a function of distance from nucleus. Curves have been smoothed to remove velocity undulations across arms and small differences between major-axis velocities on each side of nucleus. Early-type galaxies consistently have higher peak velocities than later types.

distances, were crucial in confirming the existence of dark matter in the universe and the fact that galaxies are embedded in large dark-matter halos.

We now know that most of the mass in the universe, 85 percent, is dark matter; it profoundly affects the evolution of the universe and the formation of galaxies and other structures. The dark matter is believed to be a new, exotic, as yet undetected nonbaryonic particle, not the familiar atomic elements that make up stars, gases, planets, and people. We know this from other observations that limit the amount of baryonic matter in the universe to approximately 15 percent. We don't yet know what these new exotic dark matter particles are. Many experiments have been and still are searching for these particles. Detecting and understanding their nature is one of the most important open quests in science. When asked what she thought of a theoretical suggestion that dark matter may not exist but instead a change in Newton's gravity law was needed, Vera was open minded: "I don't know if we have dark matter or need a change in gravity or need something else; we know so little about our universe. It is a strange and mysterious universe. But that's fun."

Vera continued her investigations of the dynamical properties of galaxies, their structure, morphology, mass, rotation, and more for many years to come. She found new and interesting phenomena in merging galaxies, groups of galaxies, low surface brightness and polar-ring galaxies, peculiar galaxies, and more. She enjoyed going to various observatories to do her beloved observations, bringing back the data and analyzing them at DTM. She frequently said that her happiest times were when she was in a telescope dome, observing—just she and the night-sky above.

Vera worked closely with postdocs and young scientists and served as a mentor and role model to generations of astronomers. She was a leading astronomer at DTM, attracting young astronomers, including many women, to the department. With her passing, our community lost a shining star, a pioneering scientist, a singular role model, a champion of women in science, and a close colleague and friend.

Champion of Women in Science

Early challenges as a woman in science never deterred Vera. She told her personal story in a nice autobiographical article.[1] She was denied the use of the Hale telescope at Palomar because women were not allowed access until the 1960s. She was told there was only one bathroom, and it was for men only. Vera cut a skirt-shaped piece of paper, pasted it on the bathroom door that said "Men," added "Women," and said: "Here you go; you now have a ladies room."

Vera passionately supported women scientists, always encouraging, inspiring, and helping pave their way. "Worldwide, half of all brains are in women," she liked to say. And "Don't let anyone keep you down for silly reasons," she repeated. When she was asked to write a letter of recommendation for a young woman scientist to one of the top astronomy departments, Vera told the department chair that she would write the letter as requested but would advise the student against going there because they had no women faculty. The department eventually hired women to their faculty. Her letters of recommendation to many departments frequently chastised them for not having more women on the faculty; she continuously encouraged them to do more for women. Vera would carefully watch for lists of planned conferences to ensure that enough women were listed as invited speakers; frequently she would contact the organizers to complain that they needed to add more women as speakers, and they did.

Vera was one of the most cheerful, enthusiastic, and positive people I know. She was kind, caring, and fun-loving. She had a loving family: her husband of sixty years Bob Rubin, four wonderful children, all scientists themselves, and five grandchildren.

Vera passed away on December 25, 2016, at age 88. She enjoyed a remarkable life—as a scientist, colleague, wife, mother, grandmother, and friend. I was privileged to be a close colleague and friend of Vera for many years. I miss her dearly. But her spirit and values remain forever in my heart.

"My life has been an interesting voyage," Vera wrote in 2011. "I became an astronomer because I could not imagine living on Earth and not trying to understand how the Universe works." Vera taught us how the universe works.

HONORS

Vera's seminal accomplishments have been honored with numerous awards. These include the U.S. National Medal of Science; the Gold Medal of the Royal Astronomical Society; the Gruber Cosmology Prize; the Watson Medal of the National Academy of Sciences; and many honorary degrees. Most recently, in January 2020, a highly fitting honor was announced: the naming of a major new U.S. National Observatory currently under construction in Chile (by the Association of Universities for Research in Astronomy and the National Science Foundation) as the Vera C. Rubin Observatory. This is the first major national astronomical observatory to be named for a woman. I know Vera would be delighted; she was happiest when she was observing at a telescope. Her spirit will now permanently be present at the Vera Rubin Observatory. The Nobel missed their opportunity to recognize Vera's vital observations, as they missed other important ones. Vera's legacy as the "mother" of flat rotation curves and dark matter will be forever honored, as will her legacy as a mentor to and role model for generations of scientists, men and women. Through her work and her students her star will continue to shine.

NOTES

1. V. C. Rubin. 2011. An interesting voyage. *Annu. Rev. Astron. Astrophys*. 49:1-28.
2. V. C. Rubin and W. K. Ford, Jr. 1970. Rotation of the Andromeda nebula from a spectroscopic survey of emission regions. *Ap. J.* 159:379-403.
3. M. S. Roberts. 1966. A high-resolution 21-CM hydrogen-line survey of the Andromeda nebula. *Ap. J.* 144:639-656.
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5. V. C. Rubin, W. K. Ford, Jr., and N. Thonnard. 1978. Extended rotation curves of high-luminosity spiral galaxies. IV. Systematic dynamical properties, Sa through Sc. *Ap. J. Lett.* 225:L107-L111.

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