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Famous Astronomers: Vera Rubin

The Evidence for Dark Matter

Aira Astralis

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Conclusion

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Introduction

Vera Rubin was born in Philadelphia on 23 July 1928 and died in Princeton, New Jersey, on Christmas Day 2016, at eighty eight. In the years between she did the observation that modern cosmology rests on: she measured the way galaxies spin, found that they spin wrongly, and concluded, on evidence, that the universe is mostly made of something we cannot see. The dark matter she proved is now the standard model's largest ingredient, the thing that shaped the galaxies, seeded their clusters, and holds the cosmic web in place, and the fact that a twentieth century observation of the simplest kind, a spectrum of starlight, forced that conclusion on the physics ranks among the great stories astronomy has produced.

This volume tells her life in the series' order: what happened, what she found, how it was tested, and what it left. The events divide into two braided stories. One is the science: a child watching the stars from a bedroom window in Washington, the scholarship to Vassar, the master's thesis that saw galaxy clustering decades early, the doctorate under George Gamow, the years at Georgetown with children asleep in the back of the commuting car, and the move to the Carnegie Institution, where she and the instrument maker Kent Ford took the spectra that made the rotation curves and the rotation curves made the dark matter case.

The other is the story of a woman doing science in the decades when American astronomy barely admitted women to its telescopes: the Princeton letter that rejected her because women were not admitted, the observatory that had no restroom for her sex, the nursery she demanded at the professional meetings, and the quiet, relentless insistence, in her example and her sentences, that the field's answer to the question of women was overdue.

The idea at the center deserves its own telling, because it is simpler than legend makes it. Stars in a galaxy orbit its center the way planets orbit the Sun, and in a planet system the far planets crawl, so in a galaxy the far stars should slow. They do not. In galaxy after galaxy the speeds stay flat to the visible edge and beyond, which is only possible if the outskirts are being pulled by the gravity of matter that no telescope records, and the amount of that matter, the arithmetic shows, is some six or seven times the amount that shines. Vera Rubin did not invent the dark matter hypothesis, which Fritz Zwicky had proposed for galaxy clusters in 1933 to a deaf audience, but she made it unavoidable, by measuring the individual galaxies one at a time and finding every one wrapped in its invisible mass.

The tests have kept coming for fifty years, from the radio telescopes that

traced the curves through hydrogen gas, through the gravitational lensing maps that weighed the invisible directly, to the colliding galaxy clusters whose dark matter separated from their hot gas in front of everyone's cameras, and every test has confirmed the picture her curves forced. The mystery she opened, what the dark matter is, remains the subject's biggest open question, and the observatory that will spend its first decade hunting the answer carries her name on its mountain in Chile, the first United States national observatory named for a woman.

She is in this series of astronomers on the strength of the plainest qualification there is: she looked longer and more carefully at the ordinary thing, the spinning galaxy, and saw what the whole universe is made of. The chapters that follow keep the life and the finding together, because they explain each other: the persistence the observation needed was the persistence the field had spent twenty years teaching her.

A note on the sources comes first, since the documentary record around this life is unusually intimate. Her own recollections, given in interviews across four decades and collected in the memoirs and oral histories the astronomical societies assembled, are the primary source for the childhood and the training years, and the biographers note, with something like relief, that her memory for dates and instruments was close to archival; the professional record, the papers, the observatory logbooks, and the Carnegie Institution's files, fills out the science; and the family's testimony, given freely after her death, supplies the household chapters. The volume draws on all three, and the reader should know that the famous anecdotes, the window shade, the cardboard telescope, the back seat, are the family's stories confirmed by the subject herself in her own interviews, which is the best provenance trivia gets.

The doctorate's daily shape deserves its own paragraph, because the arrangement was stranger than the summary admits. Georgetown's physics department held its classes in the evening, the arrangement made for the government's working scientists, and the young mother's doctoral program ran on the night schedule: the children fed and read to, the husband's turn at the homework, the drive across the city, the lectures under the fluorescent evening light, and the drive home past midnight, the notes written up in the car while the streetlights ticked by; the family's reminiscence holds that the youngest child, years later shown a photograph of the Georgetown observatory, identified it as the place the car always went. The biography keeps the paragraph because the era's official history has no column for this arrangement, and the science it produced had to be paid for somewhere, and the somewhere was the back seat and the night.

The Princeton rejection deserves its own paragraph, because the biographers return to it as the career's hinge. The letter, polite and brief, informed the nineteen year old graduate that the graduate astronomy program did not admit women, a policy the university's records confirm and would not change for another twenty seven years; her own account of the letter, given in interviews, was characteristically mild, that the reply told her the Princeton astronomy faculty was not open to women and that the matter had seemed, to the applicant, closed rather than worth a fight; the mildness should not be read as the era's, since the fight came, on schedule, in the decades ahead, in the meetings and the observatories where the policies were the same.

The paragraph closes with the arithmetic the episode implies: the century's decisive observer of the galaxies was, at the moment of her formation, outside the buildings the century had built for the purpose, and the outside became, as it has for several of this series' subjects, the biography's own point of origin.

Chapter 1: The Discovery of Vera Rubin

The discovery, in the series' sense, came late and was fully earned, but the observer was formed early, and the formation is a story the biographers all tell the same way.

Vera Florence Cooper was born in Philadelphia on 23 July 1928, the second of two children of Philip and Rose Cooper; the family moved to Washington, D.C., where her father, an electrical engineer, worked for the government's acoustic and electronic laboratories, and Vera's encounter with the night sky came in the ordinary way the city allowed: lying awake at ten years old, watching the stars wheel past her bedroom window, through a window shade she had cut open for the purpose. Her father answered the interest with action, walking her to amateur meetings, taking her to watch meteor showers, and, when she was about fourteen, helping her build a crude telescope from a cardboard tube and a lens; the instrument, by her own account, gathered little light and gave her the first lesson in what she would later describe as the romance of imperfection in observing.

The schools cooperated. A physics teacher, in the family's retelling, told her that as long as she stayed away from science she would do fine, advice she treated as an experiment worth failing; she won a scholarship to the scholarships' showcase, was drawn instead to Vassar College, because Maria Mitchell, the nineteenth century's first American woman astronomer, had taught there, and graduated in 1948 as the college's only astronomy major, at nineteen. Princeton's graduate school wrote back that its astronomy program did not accept women, a fact that would stand until 1975; she went instead to Cornell, where her husband, Robert Joshua Rubin, a mathematician she had married weeks after her Vassar graduation, was beginning graduate work, and she completed a master's degree in astronomy in 1951 while pregnant with her first child.

The master's thesis was the first sign of the career's whole character. Working from published catalogs, she studied the motions of 108 galaxies and found that they clustered, that galaxies traveled in company rather than uniformly, at a time when the field's picture was a smooth cosmic distribution and the suggestion was unwelcome; the thesis was presented to a professional meeting where she was, at the time, the only author in the hall with a baby, and the reception was cold, the finding dismissed as too far ahead of its data. The vindication was to come, in the 1970s and after, when the clusters and superclusters were mapped as the largest structures in existence, and the episode taught her the lesson she repeated to students all her life: do the work, publish it, and let the century catch up.

The doctorate followed the same pattern. George Gamow, the cosmologist whose office was at a neighboring Washington university, invited the young master's graduate to discuss the clustering work and then to write the doctorate under his direction, at Georgetown University, and the 1954 thesis extended the clustering case with a study of the galaxies' distribution and the suggestion that the large scale structure was real; again the idea was early, and the committee's doubts stand in the record. Georgetown then kept her, in the awkward shape the era allowed: as a research associate and lecturer, working the morning and evening with her growing family, and famously commuting the Georgetown hours with the children asleep in the car's back seat, writing her notes at stoplights, an image her later students used to summarize both the era's arrangement and her refusal of it.

The move that mattered came in 1965, when the Carnegie Institution of Washington, whose Department of Terrestrial Magnetism had quietly built one of the country's strongest astrophysics groups, offered her a research position, her first salaried permanent scientific post, at thirty six, with four children under thirteen. The institution's community gave her the colleague who completed the instrument: Kent Ford, a physicist turned instrument builder whose image tube spectrograph multiplied the power of the era's telescopes, letting a modest reflector record spectra no earlier machine could reach, and the partnership, an observer with a program and an engineer with a machine, was one of the most productive pairings in the science's history.

Their first work together was on the quasars, the decade's spectacular novelty; she made the deliberate choice, mid career, that the crowd could keep the quasars, and turned the machine toward the quiet, unfashionable subject that had drawn her at eleven: how galaxies are put together. The choice, she said later, was the whole strategy: the interesting question she could own was the one the field had assumed was already answered.

The same year, 1965, she was granted observing time on the Palomar 200 inch telescope, the era's greatest instrument, which had operated for nearly two decades as a men's facility; Margaret Burbidge had broken the barrier the year before, and Rubin became the second woman permitted to observe there, arriving to find no restroom provided for her sex and solving the problem, in the story she told for decades after, by pasting a cutout of a skirt on the door of the nearest one. The anecdote traveled the community as comedy, but the biographers read it correctly: the era's exclusion was architectural, built into the buildings, and her career's second act, the one beside the science, was the dismantling of it, at Palomar, at the meetings, and in the profession's admissions, by example, by demand, and by the plain arithmetic of the results.

The discovery of Vera Rubin by the world came in the decade of the flat rotation curves, from 1970 through 1980, as the sections ahead describe: the individual galaxy spectra with Kent Ford, the 1975 rotation curves, the 1980 sample of twenty one galaxies whose edges refused to slow down, and the slow, then sudden, conversion of a skeptical profession to the conclusion that the galaxies are mostly dark. By the 1980s the National Academy of Sciences had elected her (1981), the National Medal of Science had been awarded (1993), and the graduate schools that had rejected her were granting her honorary degrees, and the recognition, she insisted to the end, was secondary: the numbers were the point, and the numbers were hers.

A note on the words the chapter uses, offered because the field's vocabulary can mislead the general reader. Dark matter does not mean dark in the ordinary sense, a black object blocking the light; the dark means invisible, neither emitting nor absorbing enough light of any kind to register, which is why the astronomy can photograph it nowhere and still weigh it everywhere. The halo does not mean the shining ring a picture shows; it means the vast, roughly spherical region around a galaxy's disc, thin and vast and mostly empty, within which the dark matter's mass resides. And a rotation curve, the term this volume will use a hundred times, is nothing but a graph: speed on one axis, distance from the galaxy's center on the other, and the curve's shape is the galaxy's confession, read at a glance, of how its mass is truly arranged.

The reader should also carry one number into the chapters ahead, because the dark matter's case is finally an arithmetic. Take the galaxy's shining mass, its stars and gas, from the brightness of the disc; read the true mass, shining and dark, from the flat speed at the disc's edge, where the orbit's arithmetic gives the total of what holds it; and divide the second by the first. The answer, for the spirals of her sample, ran to several: five and six and seven to one, with the ratio growing at the outskirts as the flatness extends. In words, the photograph is a sixth of the galaxy, and the chapter's whole account of what she found can be compressed into that sixth, which the rest of this volume spends its pages unpacking.

One more idea belongs in the chapter's set, the one the field had to adopt before her finding could be believed, and the reader should meet it here because it is the modern cosmology's founding attitude: light is a tracer, not a census. The assumption the field had used, that the shining matter tells the mass, was convenient and wrong; the replacement attitude, that every observable is a tracer of some fraction of the truth, and that the fractions must be calibrated rather than assumed, is the working philosophy the flat curves forced, and the discipline's whole modern practice, from the lensing surveys to

the particle experiments, is the institutionalized doubt of the old assumption. The idea is her century's real legacy in the philosophy of the subject, and the chapters ahead keep finding it working.

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ABOUT THE AUTHOR

Aira Astralis is a science writer specializing in astronomy and space exploration. Her work spans the full breadth of humanity's relationship with the cosmos -- from the earliest naked-eye observations to the engineering marvels of modern space missions.

Her books are built on a foundation of primary sources: peer-reviewed research, mission archives, and direct engagement with the scientific community. She writes for readers who want to understand not just what we know about the universe, but how we came to know it.

She believes that the most important frontier is not out there but in the gap between what scientists discover and what the public understands. Her books exist to close that gap.