Chapter I:
Plenary Talks

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Honoring Charlotte Moore Sitterly: Astronomical Spectroscopy in the 21st Century
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Charlotte Emma Moore Sitterly: She "turned chaos into order"

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Abstract. At the 1988 IAU General Assembly in Baltimore, among many who offered reminiscences of earlier meetings was Charlotte Moore Sitterly. She first attended the 1932 GA meeting, in Cambridge, Mass., though she already "helped to assemble material for delegates" since the 1920s, for astronomers at Princeton, Mount Wilson and Lick Observatory. She was an ardent member of the new Commission 14 (then called "Fundamental Spectroscopic Data"), eventually becoming its president. In her 1988 reminiscence, she recalled that the Commission meeting was sparsely attended and very informal, but astronomers' "never-ending demand for tables and data analysis" soon changed all that (Sitterly 1988). Here we provide a brief overview of how Charlotte Moore Sitterly came to be at the very center of that change, which Donald Menzel early on described as having "turned chaos into order" and just a "little short of miraculous" (Menzel 1928) We will recount highlights of her early life, aspirations, training, and contributions during her years at Princeton, Berkeley, Mount Wilson, and the National Bureau of Standards.

Keywords. history and philosophy of astronomy; obituaries, biographies; methods: laboratory

1. Early Life

Charlotte E. Moore was born in 1898 in Ercildoun, a hamlet in Chester County, Pennsylvania founded by Quakers and an important stop on the Underground Railroad. The youngest of six children, both her parents, George Winfield Moore, and Elizabeth Walton Moore, were teachers there, and her father eventually became the county superintendent of schools and fostered strong educational training and maintaining a strong sense of heritage in the community (Sitterly 1978).

Education was uppermost in the family. Two brothers had died in infancy, but her eldest brother became a doctor, and her sisters were teachers, devoted to poetry and creative writing. When she graduated from public schools in the area, her family sent her to Swarthmore College in 1916. She had been well-prepared at Cotesville High School near her home, and especially liked her teachers in mathematics, history, and a bit of physics, but no exposure to laboratory work.

2. College years

Even though she seemed well prepared, Moore was intimidated by Swarthmore culture – the students who came from elite prep schools made it clear that they felt superior. She remained undecided about her major concentration. Her family was not able to fully support her, so she met living and tuition costs by teaching and tutoring. As she recalled:

> Substitute teaching and tutoring were the two fields in which a woman could get some money toward working her way through college; almost everything

> else favored the men. I taught every grade from first grade up to senior high school doing substitute work. (Sitterly 1978)

Moore resisted specializing at first, avoiding her faculty advisor, a professor of philosophy and religion. But the Dean insisted she chose a major in her sophomore year. She had accumulated enough credits in French and mathematics, so had to choose. The chair of the French department really wanted her, but Moore chose mathematics, impressed by a meeting with the head of the math department, the astronomer John A. Miller, an active producer of stellar parallaxes. At the time, astronomy at Sproul was within the mathematics department, so Moore was able to take general courses in astronomy. She recalled wanting experience using the telescope, but it was not allowed†.

As Moore neared graduation, she hoped to continue in graduate school in math, but, lacking financial support, she needed a job, though she did not want to teach. As she recalled, Miller told her that Henry Norris Russell at Princeton "was looking for somebody." Miller was willing to suggest her. She was aware of Russell's prominence in astronomy, and agreed, without visiting Princeton or meeting Russell. In her 1978 interview she implied that that was a mistake. Her only other alternative was public school teaching, which she definitely did not want to do, preferring to become what was then called a "computer."‡

3. A "computer" at Princeton

She arrived at Princeton in the Fall of 1920, and immediately realized she was out of her depth. She felt Russell's "brain was too active for the average person to follow..." and she felt overpowered. Russell gave her various assignments, like collecting information on eclipsing variable stars for the department and determining the precise position of the Moon from photographic reseau plates on a measuring machine. While she found that Russell could work "like lightning" she found him clumsy with the measuring machinery and so took it over (Sitterly 1978).

Working conditions were not pleasant. She had a workspace in an "old back room over the furnace where you breathed coal gas all the time." But Russell did encourage her to informally attend his graduate student lectures, where she was introduced to astrophysics, solar abundances, stellar evolution, and, most significantly, spectrum analysis.

By 1924, Moore had assisted Russell derive statistics for a large sample of double stars and had reduced some 88 lunar plates. She also worked for Raymond Smith Dugan compiling a catalogue of all known eclipsing binaries. But what would become her most significant work, and her first explicitly authored paper, was an extensive study of the widths of the "conspicuously winged" spectral lines in the solar atmosphere (Moore & Russell 1926).

In the 1920s solar and stellar spectroscopy, and their interpretation mainly for abundances, temperature, and pressure effects, were anything but settled. Megnad Saha's

† In the early 19th Century, American observatories were reluctant to allow women access to large telescopes. As Bessie Zaban Jones and Lyle Gifford Boyd remarked about the visual era which applied as well to the photographic era: since "observation demanded a physique that could endure constant night-long vigils in a frigid dome, astronomy remained a strictly masculine world." Jones and Boyd, 1971. The Harvard College Observatory. Harvard University Press, p. 383. There were exceptions, to be sure, and one was Berkeley and the Lick Observatory, where Sitterly did obtain her PhD.

‡ In that day computers were people, technical and not academic class. An early advertisement for "computers" tells the tale: "Miscellaneous Computers, U. S. Naval Observatory," Popular Astronomy, 15, 1907, p.448. The term has become well known due to the recent books and film titled "Hidden Figures."

ionization equilibrium theory, elaborated by Fowler and Milne, could not account for why one element would absorb energy differently than another element even though they had the same ionization potentials. A key question was the interpretation of the widths of spectral lines (Devorkin & Kenat 1983; DeVorkin 2000).

Moore did the compiling and the classification of the widths of the lines, using Rowland's classic map, supplemented by data from W. F. Meggers, then at Pittsburgh's Allegheny Observatory, and from the Mount Wilson Observatory, provided by A. S. King's laboratory work. Russell also made her aware of the applicability of multiplet structure in line identification. As Catalán had remarked in 1923, "there are many 'groups' of lines in metallic spectra that exhibit similar structure and groupings and for this form of regularity the name 'multiplet' is suggested (Catalán 1923)".

Russell directed Moore to compile lists of excitation potentials and their multiplet designations based upon his theoretical work on the "Intensities of lines in Multiplets" during his summers spent at Mount Wilson where he derived the quantum conditions that could describe the varying intensities of the lines.†

Their conclusions, issued in September 1925, with Moore, notably as first author, lent "further support to the conclusion that the widening of solar lines is primarily a result of the abundance of the atoms concerned (Moore & Russell 1926)." This was in synch with Russell's Princeton colleague John Q. Stewart, formerly a student of K. T. Compton, who had been deriving rough formulae connecting line width to the number of active atoms involved. However, once again, hydrogen was a problem, behaving quite differently than the rest of the elements. Russell speculated that hydrogen widths might be due to factors other than abundance, like the Doppler and Stark Effect. By then he was aware of the efforts of Cecilia Payne at Harvard and the hydrogen anomaly, a story many people have researched. But there were just too many problems with the theory, as is well known (DeVorkin 2010).

Throughout these years one of Moore's many responsibilities was to take Russell's handwritten notes, make them legible and edit the drafts that he wrote based upon them. By 1924, Russell introduced her to the theory of multiplets when she assisted him on his "Ultimate and Penultimate lines of Astrophysical Interest" (Russell 1925a) and his continuing identification of series in the arc and spark spectra of the metals like Titanium. As Moore recalled: "I got into the multiplet field by editing all of this material and trying to make it intelligible. Half of my time was spent editing these manuscripts." (Sitterly 1978)

Moore also assisted Stewart and others at Princeton identifying elements in stellar spectra and searching out series information. But by mid-1925 she was exhausted, finding Princeton life "very strenuous." She added "Working for Dr. Russell was really a strenuous job and you had to be on your toes all the time and I think it was just too much for me." She was not in good health, due to the pressure, and so asked Russell for a leave, mainly to work at Mount Wilson with Arthur S. King, very much along the same lines. In fact she would still be assisting Russell, but under conditions she found more amenable given King's calmer nature (Sitterly 1978).

Russell keenly knew her value to his work, publicly acknowledging that she provided "much help in tabulating and checking the data" that William Meggers and his staff provided from the National Bureau of Standards, and that King was producing with his furnaces. The largest project at Mount Wilson, in collaboration with King, Charles St. John and Harold Babcock, was the recalibration of the Rowland Tables of Solar Wavelengths, which they completed in 1928.

† Among several papers at this time, see the summary in Russell (1925b).

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4. Graduate studies

In 1928, Moore returned to Princeton, hoping to find a way to enter a formal graduate program in astronomy. It was not possible for a woman at Princeton (Landau 2019), but when Russell announced that he was taking a two-year leave to Europe with his family from 1929 through early 1931, she decided to apply to Berkeley, and was awarded a fellowship, with support from St. John, Russell and others who wrote on her behalf. She took some statistics training under Robert Trumpler, and orbit theory from Leuschner, but her thesis research came from a mountain of high-dispersion sunspot spectral data from Mount Wilson's 150-foot solar tower eagerly supplied by Adams and St. John, on the condition that she take up residence in Pasadena. Berkeley agreed willingly.

Her 1931 Thesis, "Atomic Lines in the Sun-Spot Spectrum," presented at the June 1931 meeting of the Astronomical Society of the Pacific, was the result of her analysis of some 6000 line-intensities on the revised Rowland scale (Moore 1931).

When Russell returned to Princeton he offered Moore an assistantship and promoted her to a Research Associate in 1936. Russell appreciated how valuable she had been as an assistant partly as a stabilizing influence, a factor well appreciated by Russell's family in fact. She organized and saw through to completion the many plans he kept on creating.

5. Working with Russell

As Moore recalls: "Yes. He needed somebody to stabilize him, he really did. He was always having a brilliant idea. I had very little time to plan or carry out original work. I think he didn't like that very well but how you could follow him and keep him stabilized and do original work on the side was something I found pretty baffling." And later she added "It really was a 24-hour job to work with Dr. Russell. I couldn't do the impossible (Sitterly 1978)."

But as a Research Associate she found that she enjoyed more independence as she managed Russell's enthusiasms. They worked together, from element to element through the 1930s. Some tension continued, because, as she recalled, about obtaining numerical accuracy:

> He was concerned with it, but he thought I overstressed it, always. We were always a little bit at odds about that, he thought what I was doing was entirely unnecessary. But I would never give him a list that I wouldn't stand in back of. (Sitterly 1978)

Through the 1930s she continued to work on the atomic lines in the solar spectrum, but soon added studies of phosphorus, sulphur, and ytterbium and continued her studies of the high dispersion spectra of bright early-type stars. All this was part of her creation of what she called at first "A Multiplet Table of Astrophysical Importance" which she published in a first edition in 1933. She tabulated solar wavelengths, laboratory wavelengths, identified multiplets, accounting for masking by widened solar lines, intensities, excitation potentials, with notations developed by a committee led by Russell, Allen Shenstone, and Louise Turner. Continuing along this line she published a revised and hugely expanded edition in 1945, with more to come. The 1945 edition, replacing "Importance" with "Interest" was reviewed as "extraordinary" by Marcel Nicolet and others (Nicolet 1946).

6. Marriage

Moore's life expanded when she and Bancroft Sitterly married in 1937. (Figure 1) Sitterly had been a student of Russell's after World War I, receiving his PhD in 1922.

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Figure 1. Charlotte Moore Sitterly (fourth from left) at her wedding to Bancroft Sitterly (third from left). Her new in-laws are on the left and her parents on the right. (Courtesy AIP Emilio Segrè Visual Archives, Gift of Michael A. Duncan.)

He taught at the University of Missouri and was teaching at Wesleyan in Connecticut when they were married in 1937. His main interest were eclipsing binary stars, and unlike Charlotte, he loved to teach, first at Wesleyan 1923–1945 and then at the American University from 1947–1966. Moore moved to Middletown after their marriage but remained working half-time for Russell at Princeton. The Sitterlys endured something like an academic marriage until 1945, though Moore recalls they both travelled very frequently back and forth. After Wesleyan, Sitterly spent World War II at the MIT Rad Lab until 1945 and after the war they both moved to Washington D.C., Moore to the National Bureau of Standards, and Sitterly first to the USNO, 1946–1947 and then finally to the American University, 1947–1966.

Russell was both surprised and upset that Moore decided to get married, worried that he would lose her services. He was somewhat reassured when Moore agreed to work for him half time and did through World War II working on spectroscopic problems of interest to the military. There was no question where her priorities and self-identity lay; she used her maiden name in the majority of her publications after marriage.

7. Move to the National Bureau of Standards

In 1945, Moore learned that Russell was about to retire and so she responded positively to an offer from Meggers to move to the National Bureau of Standards to take on the position of "physicist." Her husband also decided not to return to Wesleyan, taking a

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Figure 2. Bancroft Sitterly, Charlotte Moore Sitterly, and W. F. Meggers, in August, 1948. (Neils Bohr Library & Archives, American Institute of Physics, W. F. Meggers Collection.)

position first at the Naval Observatory as a result of his war work on LORAN. He then became a professor at American University in Washington, D.C.

Moore knew that physicist E. U. Condon was about to assume the NBS directorship, and in fact they arrived on the same day, November 1, 1945. But it was Meggers who first assigned her tasks and provided data for her to analyze. (Figure 2) Unlike Russell, Meggers was a laboratory observer, and was also very generous with his data. Moore's work, however, soon became redirected. Condon wanted a coherent review and analysis of atomic energy levels. Moore was given the lead, and by the early 1950s she headed a small staff and hired retired NBS volunteers as needed.

Moore was much more than a worker under Condon and Meggers. (Figure 3) She supervised the collection of data for atomic spectra for the "Committee on Line Spectra of the Elements" of the National Academy of Sciences and, partly through this and her membership on the committee, became the AAS representative to the National Academy and in a way an international focus for the collection and organization of line spectra, reaching out to American laboratories and observatories, to the Naval Research Laboratory for ultraviolet solar spectra, and to a host of Europeans:

> And they have been wonderful: Edlèn at Lund, Garton at Imperial College in Madrid; and a group under Catalán and then from the astrophysical point of view, the ones in Kiel and, of course, for solar and astrophysical work, Minnaert at Utrecht (Sitterly 1978)."

The first volume, covering Hydrogen to Vanadium, appeared in 1949, and was hailed by a reviewer in *Physics Today* as "extraordinarily accurate," well arranged and well

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Figure 3. Charlotte Moore Sitterly in her office at the National Bureau of Standards, circa 1961. (AIP Emilio Segrè Visiual Archives, gift of Michael A. Duncan.)

documented. He then added "Our gratitude for the first volume does not lessen our impatience for the appearance of the rest" which were "expected to consume five large volumes of information (Mack 1952)."

Moore retired from the Bureau of Standards in 1968 but remained as a "consultant astrophysicist" until 1971, when she moved to the Space Science Division of the U.S. Naval Research Laboratory as a "Guest Worker," holding that position until her death in 1990. Her professional papers during her tenure at the NBS (Now the National Institute of Standards and Technology) are held by its archives, and when the author inspected her office files some years ago, he found that she organized her correspondence by atomic number†.

8. In appreciation

By the 1950s Moore had become a visible central figure in the field. As Nancy Roman observed in an appreciation:

> She served the community in many other organizations. She was vice president of the American Astronomical Society and of section D of the AAAS, and president of the commission on Fundamental Spectroscopic Data of the

† Keith R. Martin to the author, 30 March 2022. "Guide to the Papers of Charlotte Moore Sitterly, 1948–1985." National Institute of Standards and Technology Archives Information Services Division.

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> International Astronomical Union. She also served on the Scientific Manpower Commission, the National Research Council committee on Line Spectra of the Elements, the International Commission of Scientific Unions committees on Spectra and on Scientific and Technical Data, and the International Union of Pure and Applied Physics Triple Union Commission on Spectroscopy (Roman 1991).

And for her service, she was a major award winner since the 1930s, recognized by many relevant professional organizations and by the nation, a recipient of the Federal Woman's Award in 1961, medals from the Department of Commerce, and the National Civil Service League Award and a Career Service Award, for which she shared an audience with President Lyndon Johnson in April 1966. At the end of my interview, I asked her to identify what she felt was her most significant contribution. Accordingly, she responded:

> Not nearly as much as I ought to have done. Oh, I don't know. I think the 1945 Multiplet Table probably. It has had the most impact. All of the multiplet tables, and now my present series, I think, probably have had the most lasting influence on astrophysics and that has been my predominant interest. I have done those tables for the astronomers more than for the physicists. My greatest pleasure over the years has come from the research on solar spectra. I am still deeply interested in the identification of solar lines as to their chemical origin.

Indeed, a rough search of the Astrophysics Data System reveals that Moore contributed some 130+ publications considered astronomical and some 80 to physics, garnering over 6,600 citations in all by the time of this writing. As Nancy Roman concluded in her obituary "She was a wonderful raconteur and a delightful person to be with" and, moreover, "Little of her work has been superseded."

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