100th Year Anniversary
Cecilia Payne-Gaposchkin
Discoverer of the Composition of the Stars

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Astronomy Associates of Lawrence

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Childhood and Early Education

- Born in Wendover, England on May 10, 1900 to middle class parents Emma and Edward Payne.
- Attended a private school run by Elizabeth Edwards.
- Learned the French and Latin languages and later in life learned German and Italian.
- A strong aptitude for geometry and algebra.
- Developed an early passion for science, particularly botany.

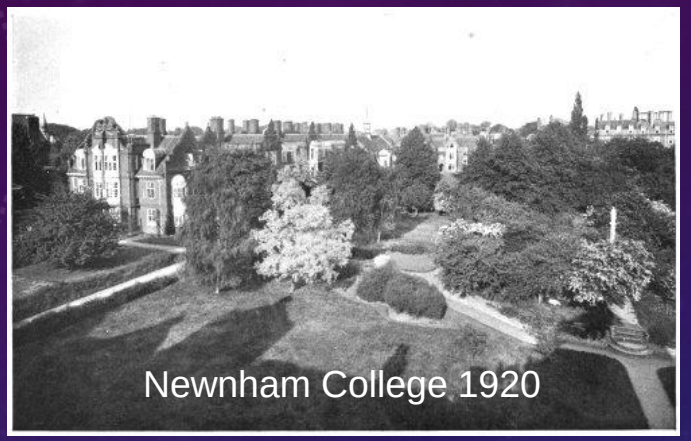
St. Mary’s Catholic School

- At the age of 12 her family moved to London so that her brother Humfry could receive a better education.
- Enrolled in St. Mary’s Catholic School.
- Received very little science instruction.
- Always carried away the top prizes.
- Not very happy and not compliant as the other girls.
- Not knowing how to deal with a high achieving girl the school in the end expelled her.

St. Paul's Girls' School

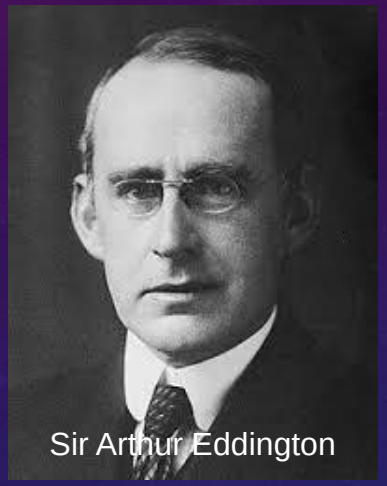
- Provided a strong science curriculum (biology, chemistry, and physics).
- Became a member of the orchestra and learned to conduct under Gustav Holst.
- Caught up on chemistry, Newtonian dynamics, thermodynamics, electricity and magnetism, and basic astronomy.
- Physics replaced her love of botany.
- Attended for one year before going on to Cambridge.

Newnham College (1919-1923)

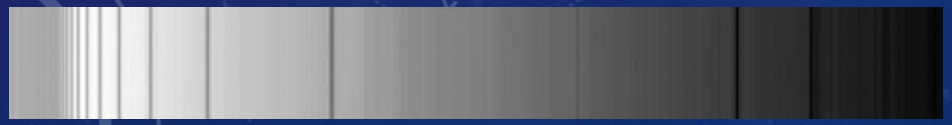

Newnham College 1920

- Enrolled in Newnham (Cambridge’s college for women) in 1919.
- Studied in Cavendish Laboratory under George Frederick Charles Searle, Niels Bohr, and Ernest Rutherford.
- Cavendish Laboratory was a very sexist environment.
- Turned to astronomy after attending a lecture, by Sir Arthur Eddington, about his confirmation of Einstein's general theory of relativity using the shift of stellar positions during the 1919 solar eclipse.

Cambridge Observatory


Sir Arthur Eddington

- Studied under Sir Arthur Eddington, W. M. Smart, and E. A. Milne.
- Learned about relativity, celestial mechanics, reduction of observations, and the chemical composition of the stars.
- Eddington (and other astronomers), at this time, believed in the uniformity of composition of celestial bodies (that all normal stars had the same composition as the earth – Planetesimal Hypothesis of Chamberlin and Moulton).
- By this time the differences in the spectra of stars was assumed to be due to temperature but the mechanism was not yet well understood.

B5V 

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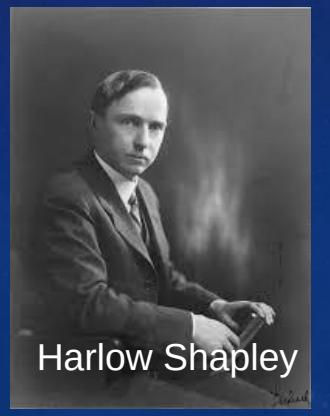
Completion of Studies

- Options after Newnham were basically limited to being a schoolmarm.
- Newnham did not confer actual degrees.
- Attended a lecture by Harlow Shapley and was inspired to go to America and work for Shapley.
- In 1920 Meghnad Saha developed a theory, using quantum and statistical mechanics, that explained the appearance of a star's spectra in terms of the temperature and pressure of the star's atmosphere.
- Milne encouraged Cecilia to test Saha’s theory using the Harvard Observatory’s library of stellar spectra to see if the uniformity in composition of the stars could be verified.

Harvard College Observatory


The Harvard Observatory Women "Computers"

- Huge collection of stellar photographs and spectra.
- A number of women were employed to measure and classify the photographic plates. These women were grossly underpaid.
- Classified stars according to the appearance of their spectra (OBAFGKM). Physical basis was unknown.
- Cecilia enrolled as a graduate student in Radcliff College (Harvard's women's college).
- She began the analysis of the spectra of hotter stars.


Harlow Shapley

Stellar Atmospheres

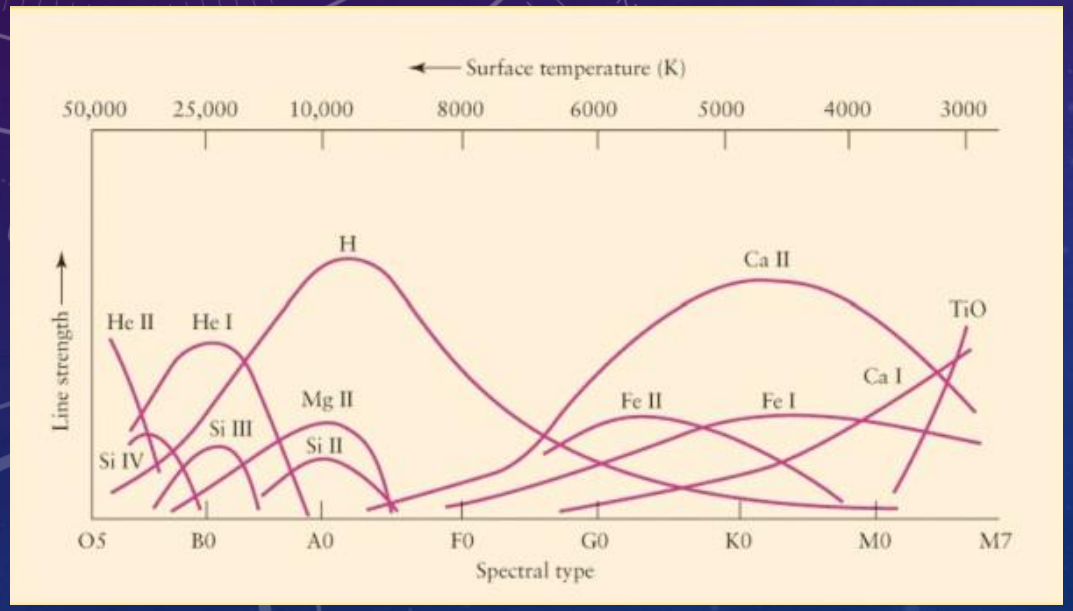
- Not trained as a spectroscopist.
- Spent two years trying to make sense of the stellar spectra.
- Applied her training in quantum mechanics and knowledge of Saha's theory, which gives the relative number of atoms in two ionization states as a function of electron density and temperature.
- Made a breakthrough with the element silicon.
- She showed that the composition of the stars are fairly uniform as Eddington said with the exception of hydrogen and helium.

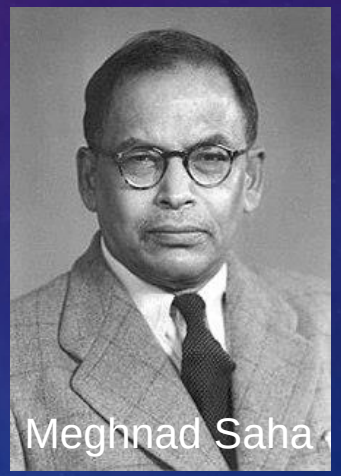
Stellar Atmospheres

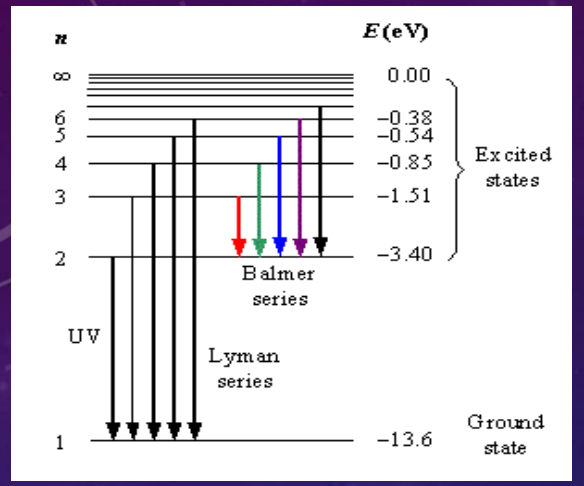
Saha Equation

$$\frac{n_{i+1}n_e}{n_i} = \frac{2}{\lambda^3}\frac{g_{i+1}}{g_i}\exp\left[-\frac{(\epsilon_{i+1}-\epsilon_i)}{k_BT}\right]$$

Observed Relative Line Strengths

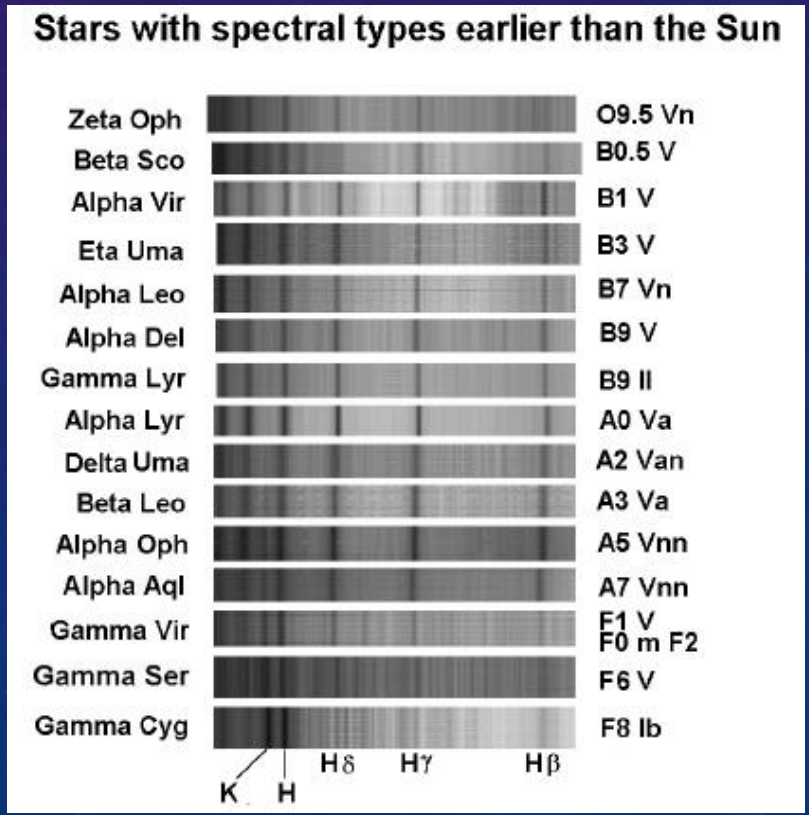




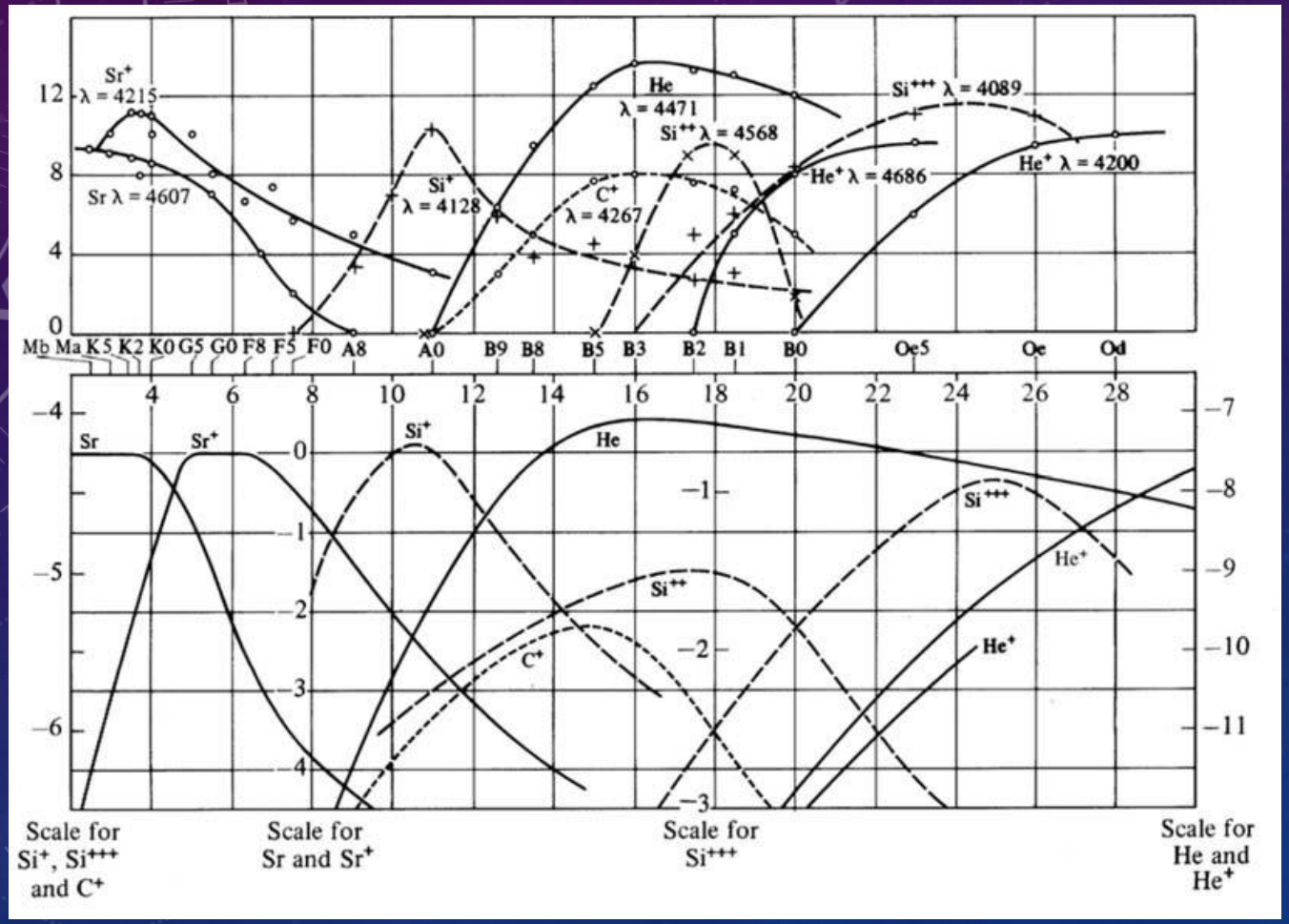


Bohr Model of Hydrogen Atom

Sample Stellar Spectra



Stellar Atmospheres



Observed Relative Line Strengths versus Predicted Line Strengths from Cecilia's Thesis

Stellar Atmospheres

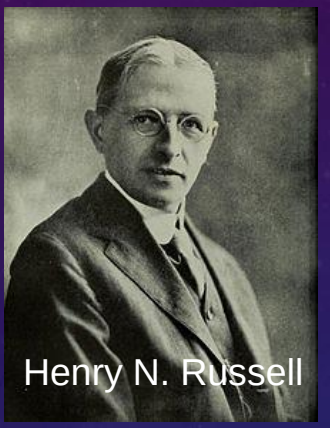
- Determined the relative abundances of the elements based on the marginal appearances of the lines of various elements. There are two marginal appearances, one at a high temperature and another at a low temperature. The marginal appearances are dependent on abundances.
- At the high temperature where a line has marginal appearance nearly all of the atoms are ionized and only a small fraction are able to absorb photons. This fraction is approximately the same for all elements. She used the Saha equation to determine this fraction, which in turn allowed her to compute the relative abundance of the elements.
- Elements other than hydrogen and helium basically had the same relative abundances as found on the earth and in stony meteorites.
- Hydrogen was about one million times more abundant than the heavier elements.
- Helium was about 1,000 times more abundant.

$$f_X = \frac{n_{X,abs}}{n_X} = \frac{\text{number of atoms of element X able to absorb photons}}{\text{total number of atoms of element X}}$$

TABLE XXVIII

Atomic Number	Atom	Log a_r	Atomic Number	Atom	Log a_r	Atomic Number	Atom	Log a_r
1	H	11	13	Al	5.0	23	V	3.0
2	He	8.3	14	Si	4.8	24	Cr	3.9
	He+	12		Si+	4.9	25	Mn	4.6
3	Li	0.0		Si+++	6.0	26	Fe	4.8
6	C+	4.5	19	K	3.5	30	Zn	4.2
11	Na	5.2	20	Ca	4.8	38	Sr	1.8
12	Mg	5.6		Ca+	5.0		Sr+	1.5
	Mg+	5.5	22	Ti	4.1	54	Ba+	1.1

Stellar Atmospheres

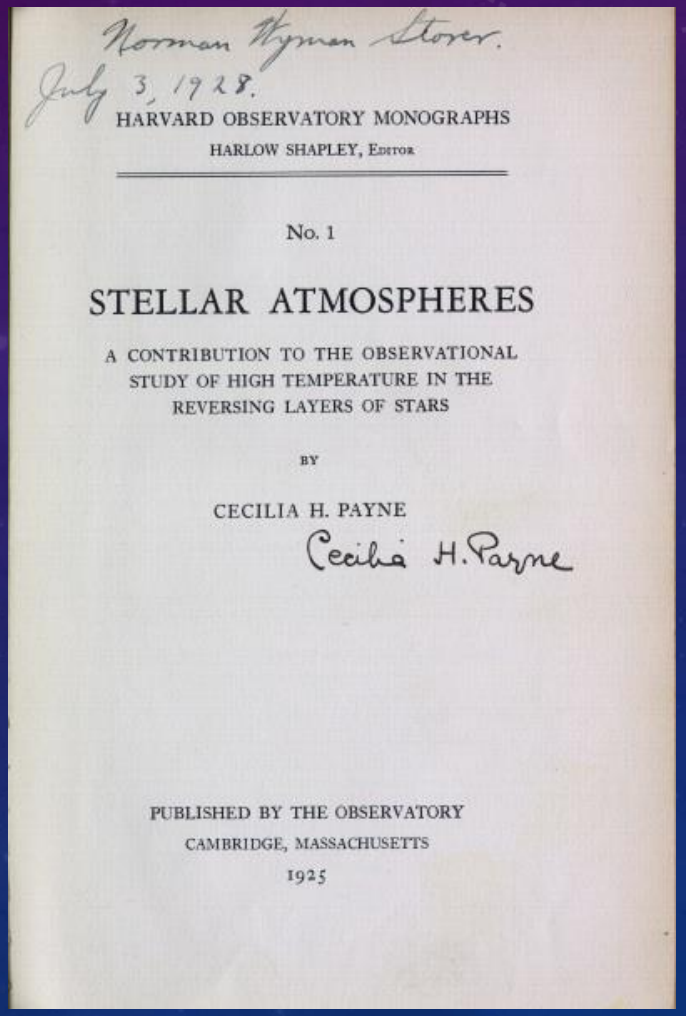

Henry N. Russell

- Thesis was published in 1925 (“Stellar Atmospheres”) and she received the first PHD in astronomy from Harvard. 650 copies were printed.
- Henry Norris Russell (reviewed her thesis) insisted that she insert a disclaimer (page 188) on the high abundances of hydrogen and helium.

> The outstanding discrepancies between the astrophysical and terrestrial abundances are displayed for hydrogen and helium. The enormous abundance derived for these elements in the stellar atmosphere is almost certainly not real. Probably the result

- Russell took four years to come around to her findings (in a 1929 paper he concluded that Celilia’s findings on the abundance of H and He were correct after his results using a different method agreed with her results) and was often given credit for it due to his prominent standing in the astronomical community.

Stellar Atmospheres


Norman Wyman Storer.
July 3, 1928.

HARVARD OBSERVATORY MONOGRAPHS

HARLOW SHAPLEY, Editor

No. 1

STELLAR ATMOSPHERES

A CONTRIBUTION TO THE OBSERVATIONAL STUDY OF HIGH TEMPERATURE IN THE REVERSING LAYERS OF STARS

BY

CECILIA H. PAYNE

Cecilia H. Payne

PUBLISHED BY THE OBSERVATORY

CAMBRIDGE, MASSACHUSETTS

1925

"…the most brilliant PhD thesis ever written in astronomy."

Otto Struve - 1962

Career After Receiving Her Degree

- Continued to work at the Harvard Observatory without a title (Harvard President Lawrence Lowell: “Miss Payne should never have a position in the University while I am alive”).
- Many career opportunities were deflected by Harlow Shapley.
- 1934: Married Sergei Gaposchkin, a Russian astronomer.
- 1934: First recipient of the Anne J. Cannon Prize from the American Astronomical Society.
- Specialized in study of variable stars.
- After Shapley retired as director his replacement Donald Menzel doubled Cecilia’s salary.

Later Years

- 1956: became the first woman to be promoted to a full professorship at Harvard followed by the first woman to chair a department a few months later.
- 1961: Received the Rittenhouse Medal from the Franklin Institute.
- 1962: Last PhD student was Owen Gingerich.
- 1976: First woman to receive the Henry Norris Russsell Prize from the American Astronomical Society.
- 1979: Passed away after a battle with lung cancer.

Other Books by Cecilia Payne-Gaposchkin

- The Stars of High Luminosity (1930)
- Variable Stars (1938)
- Variable Stars and Galactic Structure (1954)
- Introduction to Astronomy (1954)
- The Galactic Novae (1957)

More Recent Acknowledgments

- 2008: Institute of Physics Cecilia Payne-Gaposchkin Medal and Prize named in her honor.
- 2014: Featured in Episode 8 of the Cosmos Series that aired on Fox Television.
- 2018: The American Physical Society's Doctoral Dissertation Award in Astrophysics was renamed the Cecilia Payne-Gaposchkin Doctoral Dissertation Award in Astrophysics.
- Namesake of one of the ASAS-SN telescopes deployed in South Africa.
- Namesake of the Payne-Gaposchkin Patera (volcano) on Venus.

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Questions?