Prior to the nineteenth-century, little is written of women’s contributions in astronomy. In most astronomy texts, you will find no mention of Hypatia of Alexandria, considered the first woman astronomer. Most historians consider her brutal death in the early fifth-century to be the beginning of the “Dark Ages.” There is no mention of Hildegard von Bingen (1099-1179) whose ideas on “universal gravitation” predate Isaac Newton’s, nor Sophia Brahe, Tycho’s younger sister. It was not until the director of Harvard Observatory became disgruntled with the sloppy work of his male assistant, saying his housekeeper could do better, that women were readily accepted into the study of astronomy.

Harvard College Observatory was founded in 1839, a time when astronomy was beginning to be taught as a science subject in its own right, instead of as an extension of philosophy. This was also a time when universities were receiving funds for astronomical research, an endeavor previously pursued by learned men of means.

Astronomy is a science requiring observations and exact calculations, particularly of positions of celestial objects. This was tedious work completed by “computers.” Originally, young men performed these tasks. This changed when Edward Charles Pickering became director of the observatory in 1877 and opened the doors of astronomy to women.

Pickering was sympathetic to the women's suffrage movement and recognized that there was a new breed of women, women that were educated. He also realized that with the new technologies of the time, telescopes that were readily available and astrophotography, that the data collection was happening faster than could be catalogued so as to be useful. Although women had been volunteers at the observatory in the past, usually relatives of men on Harvard's payroll, Pickering convinced the Harvard Corporation to hire women for the tedious work of "computers." This occurred none too soon as Harvard College Observatory would be asked to complete a task of astronomical proportions.

The women computers at Harvard College Observatory became known as “Pickering’s Harem,” an unflattering term. It is unknown if they were bothered by this. What is known is that they appreciated the opportunity he gave them, to work in the science they loved and to become some of astronomy’s brightest stars.

This picture which includes Edward Charles Pickering, the Director of HCO (1877-1919), was taken on 13 May 1913 in front of Building C, which faces north. At that time it was the newest and largest building of Harvard College Observatory. It was specially built of brick to protect the astronomical data and glass negatives from fire. Since the astronomical photographs were stored on the ground floor and most of the women worked on the top floor, the building had a dumb waiter to convey the plates up and down. The women all worked in a large room on the east end of the third floor. Pickering had his offices on the west end across the central hallway. All the other men worked on the lower levels.

THE 'HARVARD COMPUTERS'- (late 1800s- early 1900s) CAN YOUR COMPUTER GIVE BIRTH, BAKE OATMEAL COOKIES, OR DANCE A MEAN VIRGINIA REEL? THE EARLIEST 'COMPUTERS” AT HARVARD COULD.

In the late 19th Century they had their own floor in the Harvard Observatory; a fine building made of bricks to protect valuable astronomical data. At long wooden tables, amid stacks of notebooks, the women known as The Harvard computers poured over images of light. New spectra graphic technology made it possible to photograph light patterns around stars. These women painstakingly performed complex calculations needed to process data from those images. Their work helped determine the positions and composition of stars.

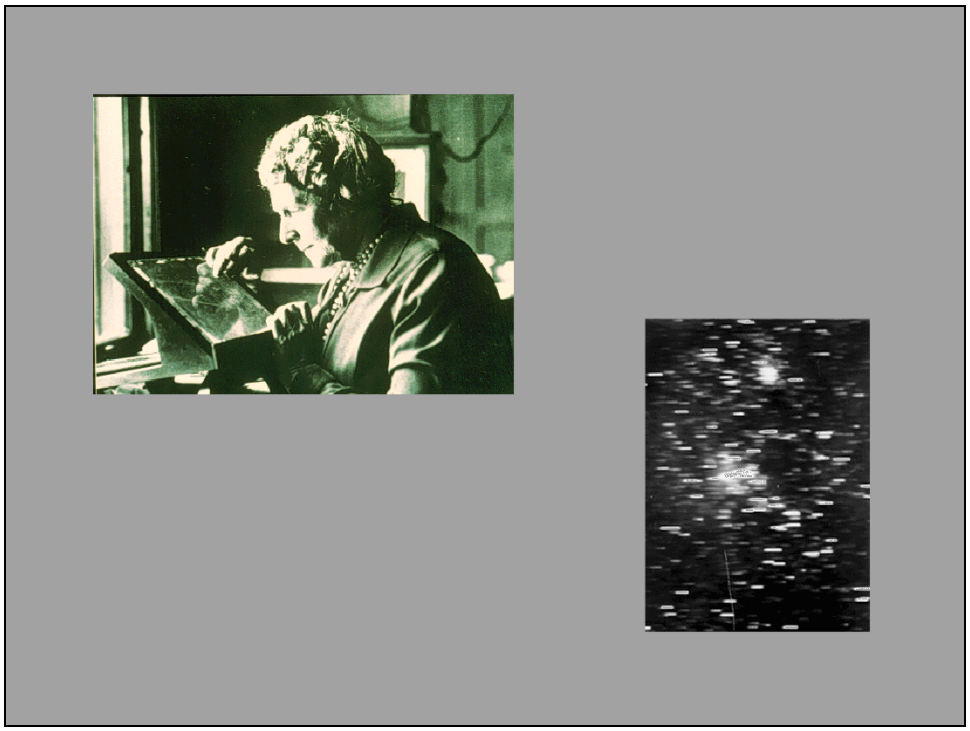
Astronomer and Observatory Director Edward Charles Pickering assembled this task force of human 'computers' at the end of 19th Century. Known as 'Pickering's Women' or less flatteringly, 'Pickering's Harem' and eventually, 'the female computers', they were former teachers, recent college graduates and single mothers. One had even been Pickering's housekeeper. They were paid 25 to 50 cents an hour. Half what men would have earned for the same work. The “computers” developed classification systems that identified nearly 400,000 stars. They published nine volumes of the Henry Draper Catalog, still used by astronomers today, and their work is used to produce modern stellar maps.

The roster of Harvard Computers reads like a Who's Who of astronomers. Through the years they built upon each other’s work. Williamina Fleming supervised the observatory for 30 years-working with Pickering on the first system to classify stars by spectrum. Antonia Maury helped locate the first double star, and developed her own classification system. Henrietta Leavitt developed a law to determine stellar distances. The most famous of the Harvard computers was Annie Jump Cannon. An expert in photography, she cataloged over 350,000 stars and developed the classification system used today.

Henry Draper (1837-1882) was a man of means, a physician, an amateur astronomer, and a pioneer of astrophotography. He almost certainly acquired his interest in astronomy from his father, John William Draper, who took the first daguerreotype of the Moon in the winter of 1839-1840. Henry Draper also had many firsts in his short life. He took “the first photograph of an astronomical nebula, recording the Great Nebula of Orion on the night of September 30, 1880...the first stellar spectrum photograph, which he took of Vega in August 1872, the first wide-angle photograph of a comet’s tail, and the first spectrum of a comet’s head, both of these with Tebbutt’s Comet in 1881.” Draper "also invented the slit spectrograph and pushed the state of the art in photography, instrumental optics, and telescope clock drives.”

It was his intention to photograph the entire night sky, to create a complete spectral catalogue that would be available to others for their research. He did not realize his dream due to his untimely death at age 45, the result of double pleurisy after a hunting trip to the Rocky Mountains. It was his widow, Anna Mary Palmer, who did not let his dream die. She donated money to the Harvard College Observatory to complete this monumental task in honor of her husband.

It was indeed fortuitous that Pickering had hired women to perform the tiresome task of cataloguing and computing. The women’s beginning wage was about $.25 per hour, less than half that paid to men doing the same task. Pickering was able to double his staff of computers by hiring women. And as Pickering was to find out, the women also did a better job.



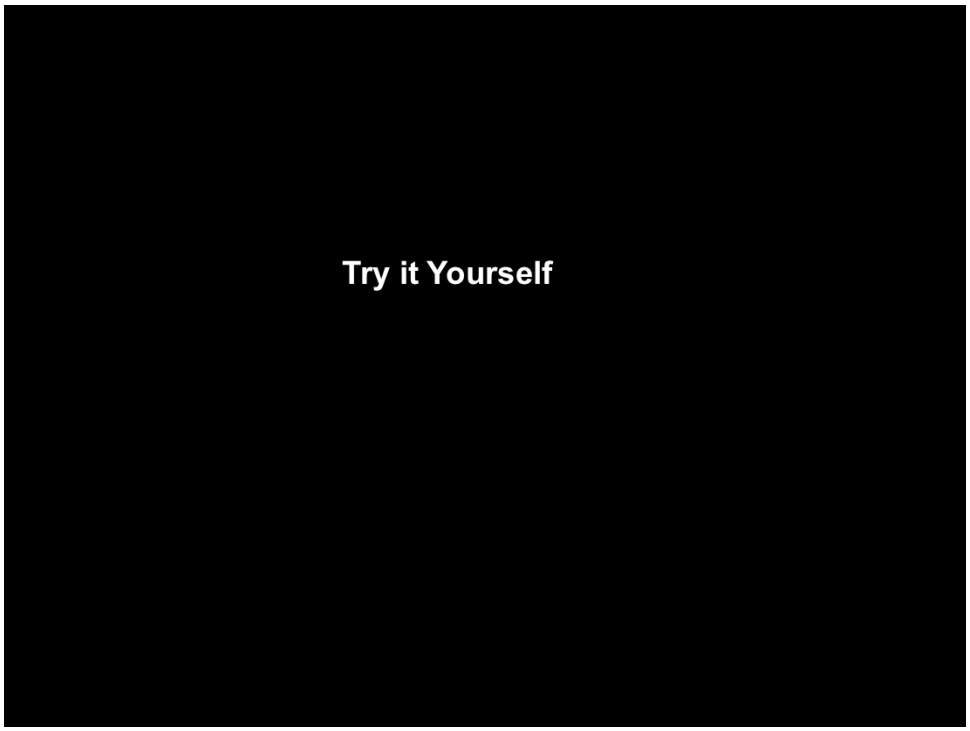
At the turn of the century the new science of astrophysics was growing rapidly, due to the recent findings in photometry and spectroscopy. When Annie began at Harvard scientists knew that when light from the Sun was shone trough an prism it was dispersed into a spectrum of component colors, like a rainbow. The spectrum was broken up by a series of dark lines and bands which resulted from various atoms in the solar atmosphere. After astronomers like Prof. Pickering attached prisms to their telescopes and took photographs of other stars they discovered that the lines in the spectra of stars differed from those of the Sun. Stellar classification according to line patterns began. This was not easy to do. Annie excelled because of her sharp eye and memory. The following image is one photographic plate containing stellar spectra. For this particular field she averaged 3 stars a minute.

Annie Jump Cannon was the eldest child of Wilson Lee Cannon, a successful ship-builder and state senator, and Mary Elizabeth, his second wife. She was born in Dover, Delaware on December 11, 1863 and as a young girl became enthralled with astronomy from excursions with her mother who taught her the constellations. Cannon graduated from Wellesley College in 1884 where she studied physics and astronomy with famed professor Sara Whiting.

For the next eleven years, Cannon studied music and traveled. It was during this time, after a bout of scarlet fever, that she lost her hearing. Upon the death of her mother, she decided to pursue her interests in astronomy and went to Radcliffe College as a “special student” for two years. Edwin Pickering was instrumental in her obtaining this special status. In 1896, she joined the ranks of computers at Harvard College Observatory.

Cannon’s duties included cataloguing variable stars and classifying the spectra of stars in the southern hemisphere for the Henry Draper Catalogue project, the counterpart to Maury with the northern hemisphere. In her free time, Cannon poured over the observatory’s photographic plate collection, studying variable stars.

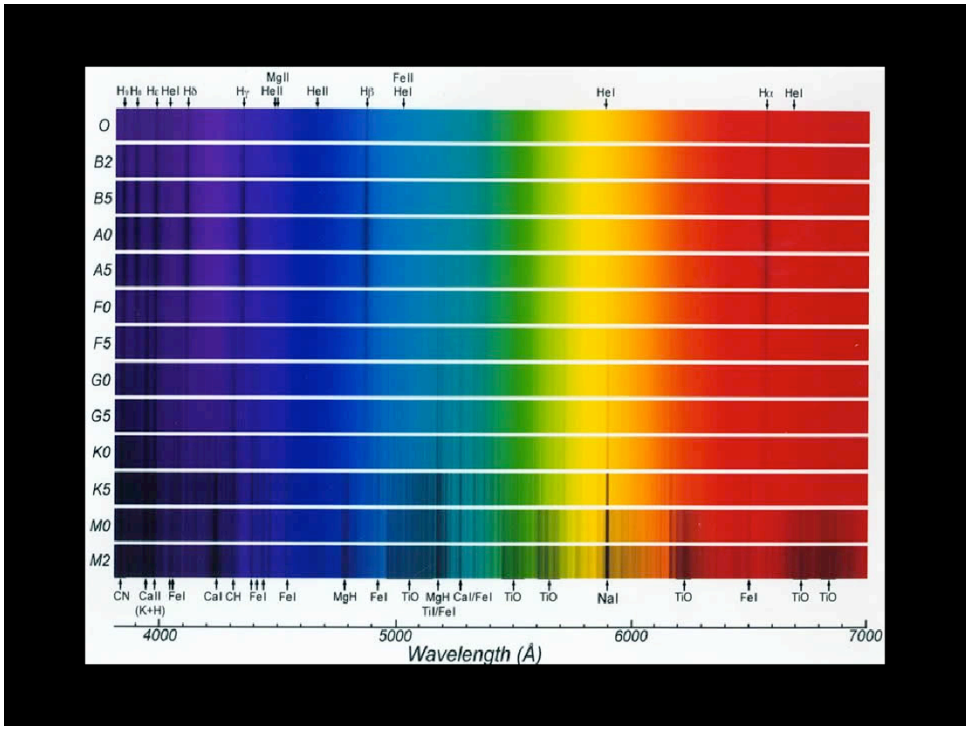
Possibly due to her deafness, Cannon was “recognized even during her lifetime as the world’s expert in identifying and classifying stars, with incredible accuracy and speed.” By the time of her death, she had classified up to 350,000 stars, at a rate of up to 300 per hour.



Have students use spectra and grid to analyze Cannon’s classification.

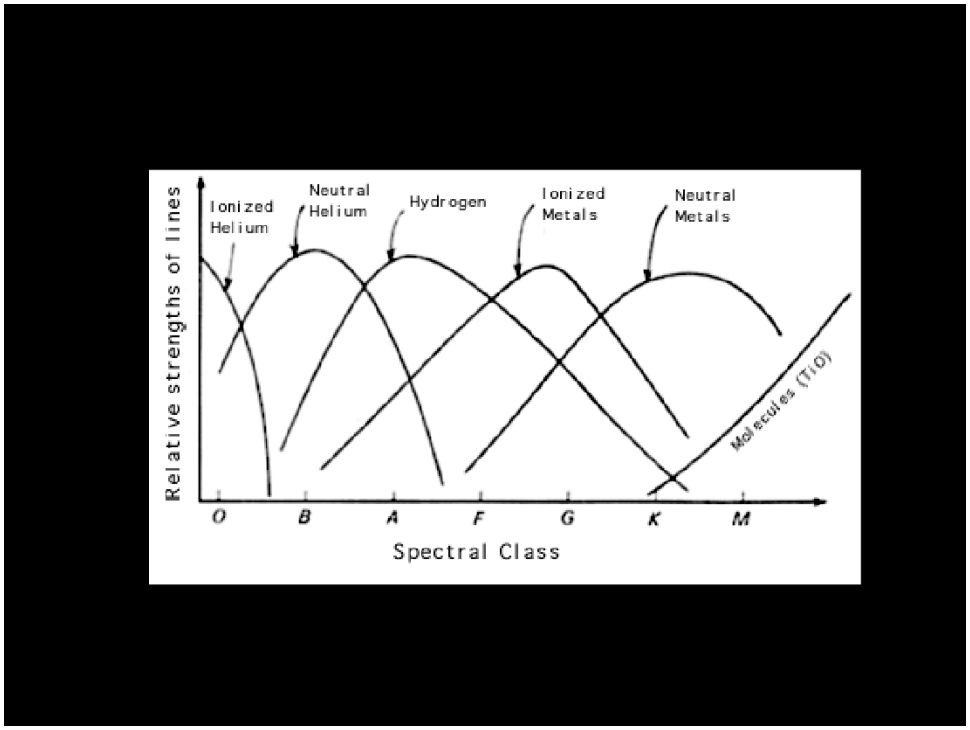
First sort by A-O looking at Hydrogen lines and looking for patterns. The first women sorted by this, looking at the strength of the lines.

They only knew temperature of star from the color. Elements in stars were known by emission/absorption lines.



Cannon's classification. She saw the relationship to temperature

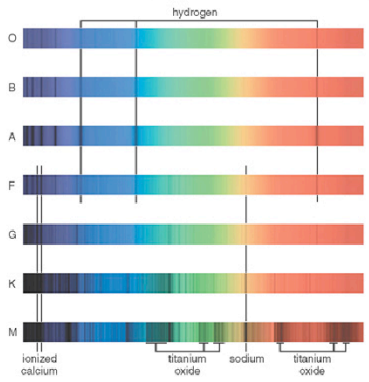
Use star cards to check color and temperature.



While the differences in spectra might seem to indicate different chemical compositions, in almost all instances, it actually reflects different surface temperatures. With some exceptions (e.g. the R, N, and S stellar types discussed below), material on the surface of stars is "primitive": there is no significant chemical or nuclear processing of the gaseous outer envelope of a star once it has formed. Fusion at the core of the star results in fundamental compositional changes, but material does not generally mix between the visible surface of the star and its core.

TABLE 11.1 *The Spectral Sequence*

Spectral Type	*Example(s)*	*Temperature Range*	*Key Absorption Line Features*	*Brightest Wavelength (color)*
O	Stars of Orion's Belt	730,000 K	Lines of ionized helium, weak hydrogen lines	97 nm (ultraviolet)*
B	Rigel	30,000 K–10,000 K	Lines of neutral helium, moderate hydrogen lines	97–290 nm (ultraviolet)*
A	Sirius	10,000 K–7,500 K	Very strong hydrogen lines	290–390 nm (violet)*
F	Polaris	7,500 K–6,000 K	Moderate hydrogen lines, moderate lines of ionized calcium	390–480 nm (blue)*
G	Sun, Alpha Centauri A	6,000 K–5,000 K	Weak hydrogen lines, strong lines of ionized calcium	480–580 nm (yellow)
K	Arcturus	5,000 K–3,500 K	Lines of neutral and singly ionized metals, some molecules	580–830 nm (red)
M	Betelgeuse, Proxima Centauri	3,500 K	Molecular lines strong	830 nm (infrared)



* All stars above 6,000 K look more or less white to the human eye because they emit plenty of radiation at all visible wavelengths.

The scheme is based on lines which are mainly sensitive to stellar surface temperatures rather than actual compositional differences, gravity, or luminosity. Important lines are the hydrogen Balmer lines, lines of neutral and singly ionized helium, iron lines, the H and K doublet of ionized calcium at 396.8 and 393.3 nm, the G band due to the CH molecule, the 422.7 nm neutral calcium line, several metal lines around 431 nm, and the lines of titanium oxide.

Cannon refined the cataloguing schemes of her predecessors, Fleming and Maury. With Fleming's scheme, she reduced the categories to seven and arranged them by temperature, from high to low, leaving OBAFGKM. With Maury's system, instead of lower-case letters, Cannon used numbers from 1-10 to reflect gradation within each category. Her category scheme was so "user-friendly," it was officially adopted as the standard in 1910 by the International Astronomical Union. Today, with minor changes, Cannon's system is known as the Harvard Spectral Classification.

O h,
B e
A
F ine
G irl
K iss
M e

Cannon worked at Harvard College Observatory for 45 years, until her death at age 77 from heart failure and arteriosclerosis on April 13, 1941. During that time, Cannon took over the duties as Curator of Astronomical Photographs when Fleming died in 1911. Cannon also published several volumes of catalogues, including her "Provisional Catalogue" in 1903, with a revision in 1907 listing 1,957 variable stars and their discoverers, the most complete list of its kind at the time. She also revised the *Henry Draper Catalogue* down to 8th magnitude, published in sections between 1918 and 1924.

Cannon was recognized by her peers for her contributions to astronomy. She received six honorary degrees, one from Oxford University, the first given to a woman, and was the first woman to receive the Draper Gold Medal. With the money she received from one award, the Ellen Richards Research Prize of the Association to Aid Scientific Research by Women, Cannon established an award to recognize contributions to astronomy by women.

Oh Be A Fine Girl, Kiss Me!

Official Bureaucrats At Federal Government Kill Many Researchers' National Support

Oh Boy! Another Failing Grade Keeps Me Reconsidering Night School.

Obese Balding Astronomer Found Guilty Killing Many Reluctant Nonscience Students.

Out Beyond Andromeda, Fiery Gases Kindle Many Radiant New Stars

One Bug Ate Five Green Killer Moths.

Old Bottles And Filthy Garbage Kill Many Rare Natural Species

N, S, R – Also known as C – Red Giant Variables
WC & WN – Wolf-Rayet stars
L & T – Cool Dwarfs

According to astronomical myth, Henry Norris Russell suggested the following mnemonic to assist students in remembering the scheme

A number of giant stars appear to be K or M type stars, but also show significant excess spectral features of carbon compounds. They are often referred to as "carbon stars" and many astronomers collectively refer to them as C type stars. The most common spectral features are from C2, CN, and CH. The abundance of carbon to oxygen in these stars is four to five times higher than in normal stars. The presence of these carbon compounds will tend to absorb the blue portion of the spectrum, giving R and N type giants a distinctive red colour. R stars are those with hotter surfaces which otherwise more closely resemble K type stars. S type stars have cooler surfaces and more closely resemble M stars.

Instead of (or in addition to) the usual lines of titanium, scandium, and vanadium oxides characteristic of M type giants, S type stars show heavier elements such as zirconium, yttrium, and barium. A significant fraction of all S type stars are variable.

Wolf-Rayet stars are similar to O type stars, but have broad emission lines of hydrogen and ionized helium, carbon, nitrogen, and oxygen with very few absorption lines. Current theory holds that these stars exist in binary systems where the companion star has stripped away the Wolf-Rayet star's outer layers. Thus the spectra observed is from the exposed stellar interior rather than the normal surface material. The broadness of the lines also indicates that the material observed may be from high velocity gases streaming away from the star, with the range of velocities smearing out the observed lines.

L & T shine in the red & infrared part of the spectrum

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Many of these women went on to become scientists in their own right, as the field opened up to women.

Margaret Harwood (AB Radcliffe 1907, MA University of California 1916), who had just completed her first year as Astronomical Fellow at the Maria Mitchell Observatory. She was later appointed director there, the first woman to be appointed director of an independent observatory.

Johanna Mackie, an assistant from 1903 to 1920. She received a gold medal from the American Association of Variable Star Observers (AAVSO) for discovering the first nova in the constellation of Lyra.

Ida Woods (BA Wellesley 1893), who joined the corps of women computers just after graduation. In 1920 she received the first AAVSO nova medal; by 1927, she had seven bars on it for her discoveries of novae on photographs of the Milky Way.