1. Thank you for inviting me.

2. Theme of convention is "Crossroads of Astronomy." Talk about Five Remarkable Women at the Crossroads of Astronomy.

3. Guess who this is. It is a poem in the form of a fictional letter written to the astronomer's sister:

A poem by Siv Cedering (1986):

William is away, and I am minding
the heavens. I have discovered
eight new comets and three nebulae
never before seen by man,
and I am preparing an Index to
Flamsteed's observations, together with
a catalogue of 560 stars omitted from
the British Catalogue, plus a list of errata
in that publication. William says
I have a way with numbers, so I handle
all the necessary reductions and
calculations. I also plan
every night's observation
schedule, for he says my intuition
helps me turn the telescope to discover
star cluster after star cluster.

I have helped him polish the mirrors
and lenses of our new telescope. It is
the largest in existence. Can you imagine
the thrill of turning it to some new
corner of the heavens to see
something never before seen
from earth? I actually like
that he is busy with the Royal Society
and his club, for when I finish my other work
I can spend all night sweeping
the heavens.

Sometimes when I am alone
in the dark, and the universe reveals
yet another secret, I say the names
of my long, lost sisters, forgotten
in the books that record
our science--

Aganice of Thessaly,
Hyptia,
Hildegard,
Catherina Hevelius,
Maria Agnesi

--as if the stars themselves could remember.

Did you know that Hildegard
proposed a heliocentric universe
300 years before Copernicus? that she
wrote of universal gravitation 500 years
before Newton? But who would listen
to her? She was just a nun, a woman.
What is our age, if that age was dark?
As for my name, it will also be
forgotten, but I am not accused
of being a sorceress, like Aganice,
and the Christians do not threaten to
drag me to church, to murder me, like they did
Hyptia of Alexandria, the eloquent, young
woman who devised the instruments
used to accurately measure the position
and motion of heavenly bodies.

However long we live, life is short, so I
work. And however important man becomes,
he is nothing compared to the stars.
There are secrets, dear sister, and it is
for us to reveal them. Your name, like mine,
is a song.

Write soon,

Caroline

4. Answer: Poem's title is

"Letter From Caroline Herschel (1750-1848)"

5. **Caroline Herschel (1750 - 1848)**

Born in Hanover, Germany - father a musician, four brothers all trained as musicians.

Typhus at age ten. Never grew taller than four foot three.

Caroline's mother wanted Caroline to be her house servant

Father encouraged her to improve herself.

Caroline recalled that her father took her
... on a clear frosty night into the street, to make me acquainted with several of the beautiful constellations, after we had been gazing at a comet which was then visible.

1766 - Brother William became an organist in Bath

Six years later William brought Caroline (age 22) to Bath to be his housekeeper.

William gave Caroline voice lessons - she became the most prominent soprano in Bath.

William's hobby was astronomy. He was obsessed with seeing deeper and deeper into space.

After Caroline arrived, he became known as a great telescope maker.

Caroline did not share her brother's passion for the science. William trained her in mathematics, yet she was still a house maid, not his apprentice.

Caroline never learned her multiplication tables. Carried a table on a sheet of paper in her pocket when she worked.

Still, she learned spherical trigonometry (important for reducing astronomical observations).

1781 - William discovers Uranus. King George III gives William a £200 per year salary (just enough to become a full-time astronomer).

Caroline began to help - long hours grinding and polishing the mirrors (tin and copper alloy).

Age 32, she became an apprentice to her brother.

William wrote: "When everything was in readiness, we put our 537.9 pounds of metal into the melting oven and gradually heated it. Before it was sufficiently fluid for casting we perceived that some small quantity began to drop through the bottom of the furnace into the fire. The crack so increased and the metal came out so fast that it came out of the ash hole which was not lower than the stone floor of the room. When it came upon the pavement the flags[tones] began to crack and some of them to blow up, so that we found it necessary to keep a proper distance and suffer the metal to take its own course."

Caroline wrote: *Every leisure moment was eagerly snatched at for resuming some work which was in progress, without taking time or changing dress, and many a lace ruffle ... was torn or bespattered by molten pitch. ... I was even obliged to feed him by putting the vitals by bits into his mouth; - this was once the case when, at the finishing of a* 7 *foot mirror, he had not left his hands from it for* 16 *hours ...*

When William would leave on business, she would take over in his place.

Visitors began to recognize her authority.

King George III gave her a pension of fifty pounds - the first time a woman was recognized for a scientific position.

Caroline's first accomplishments - the detection of nebulae.

William gave her a small telescope with which to look for comets.

She discovered 14 nebulae, including, NGC 891 and NGC 253.

William married - spent less time at the observatory - Caroline carried on her work.

Caroline discovered eight comets between 1786 and 1797.

Embarked on a new project of cross-referencing and correcting the Flamsteed's 1798 star catalogue.

Caroline submitted to the Royal Society an Index to Flamsteed's Observations of the Fixed Stars together with a list of 560 stars which had been omitted.

This marked the temporary end of her own researches which she would not begin again until 25 years later.

In the meantime, she became involved with the education of John Herschel, her nephew.

John was educated at Cambridge, made a name for himself as a mathematician, became elected to the Royal Society, and joined his father in research in astronomy.

After William's death in 1822, Caroline catalogued every discovery that she and William had made.

She was made an honorary member of the Royal Astronomical Society and the Royal Irish Academy.

The King of Prussia gave her the Gold Medal of Science for her life's accomplishments.

Fortunately, the name of Caroline Herschel has not been forgotten!

6. Some important questions for early astronomy

   What types of stars are there?

   How far away are stars and nebulae?

   What are stars made of?

7. Answers came from the three founders of modern astronomy.

8. What types of stars are there?

Annie Jump Cannon (1863 - 1941)

Annie's mother taught her the constellations and stimulated her interest in astronomy.

Her father was a shipbuilder and a state senator.

She suffered a handicap in her youth, and was very hard of hearing.

Wellesley College - Annie studied physics and astronomy and learned to make spectroscopic measurements.

1894 - after mother's death, Annie worked at Wellesley as a junior physics teacher.

Became a "special student" of astronomy at Radcliffe.

Historical background - - - - -

1872 - Annie was four years old when Henry Draper took the first spectrum of a star.

1885 - His widow established a stellar spectroscopy fund at Harvard as a memorial to Henry.

The project was headed by Edward Pickering (Harvard College Observatory director).

Pickering was a taxonomist, not a theorist: "the first step is to accumulate the facts."

Mrs. Williamina Fleming (a “computer” for Pickering) divided the first set of glass-plate spectra into thirteen types (A B C D E F G H I K L M N - no J!)

Miss Antonia Maury (Henry Draper’s niece) invented her own system of spectral types - introduced a precursor of luminosity classes.

End of History - - - - -

1896 - Annie becomes one of "Pickering's Women," - 50 cents/hr

Harlow Shapley (later director of Harvard Observatory) wrote, in 1948:
"On May 14, 1896, Annie J. Cannon made her first recorded observation of the spectra of stars ... For her first spectrum classifications Miss Cannon used plate B 9431 [a portion of which is shown at right] *which was made with an exposure of 140 minutes in 1893. A glance at that remarkable early photograph will suggest why Miss Cannon was captivated by stellar spectra and was led to devote a long and happy career to the classification of faint stars."*

The speed with which Annie worked was phenomenal.

Classified 5,000 stars per month between 1911 and 1915.

She would examine the photographic plate and call out a letter for each spectrum to an assistant.

Annie achieved a rate of more than 3 stars a minute.

Annie used Williamina Fleming’s system, rearranged it, and introduced decimal subdivisions.

The result was O B A F G K M. “Oh be a fine girl/guy kiss me.”

1909 - the first stellar temperatures were measured by Charles Nordmann - this spectral sequence was discovered to be a temperature sequence. The halmark of a successful taxonomy!

1911 - Annie appointed curator of astronomical photographs at the Harvard College Observatory.

Five years later, she became an honorary member of the Royal Astronomical Society in England.

1918 -- 1924 - published 9 volumes containing information about 225,000 stars. It was published with the title *Henry Draper Catalog*.

The catalog is still accepted as an international standard.

Annie wrote:
Classifying the stars has helped materially in all studies of the structure of the universe. No greater problem is presented to the human mind. Teaching man his relatively small sphere in the creation, it also encourages him by its lessons of the unity of Nature and shows him that his power of comprehension allies him with the great intelligence over-reaching all.

1925 - first woman to receive an honorary doctorate from Oxford University.

She was the first woman elected an officer of the American Astronomical Society.

1931 - the first woman to be awarded the National Academy of Science's Draper Gold Medal (1931).

Catalogued 350,000 stars during her lifetime.

Discovered five novas and about 300 long-period variable stars.

1938 - Harvard University finally awarded her a rank of professor just two years before her retirement.

Months before her death in 1941 in a letter to one of her classmate she wrote:
"At the Observatory, I am classifying, classifying and now getting ready to start on a large piece for Yale Observatory. It will be a job! And will keep several assistants busy doing minor details. Of course I love to do it."

9. A photo of Pickering's computers in 1918. He wrote:
"[These women] are capable of doing as much good routine work as astronomers who would receive much larger salaries. Three or four times as many assistants can thus be employed, and the work done correspondingly increased for a given expenditure."

10. How far away are the stars and nebulae?

Hentrietta Swan Leavitt (1868 - 1921)

Born in Massachusetts, one of seven children of a well-known Protestant minister from an old American family.

1892 - senior at Radcliffe - became interested in astronomy.

After graduation she took another course in it, but then spent several years at home - suffered a serious illness that left her severely deaf.

1895 - Henrietta started working for Pickering at Harvard's Observatory, first as a volunteer - then on staff for 30 cents/hr.

1907 - began working on Pickering's project to obtain standardized values for stellar magnitudes.

Along the way, she discovered of 4 novas and some 2,400 variable stars.

1912 - Henrietta observed Cepheid variable stars in the Small Magellanic Cloud.

Compared photographic plates to see if any star's brightness changed regularly.

Discovered that brighter Cepheids have longer periods.Henrietta wrote:
"A straight line can be readily drawn . . ., thus showing that there is a simple relation between the brightness of the variable and their periods."

Henrietta also realized that "since the variables are probably nearly the same distance from the earth, their periods are apparently associated with their actual emission of light, as determined by their mass, density, and surface brightness."

The Cepheids were in the Small Magellanic Cloud are all at the same distance from Earth (200,000 ly).

Henrietta realized that stars' periods must depend not on how bright they appear ("apparent" luminosity), but how bright they really are ("intrinsic" or "absolute" luminosity).

This is her period-luminosity relation. It still had to be calibrated using a Cepheid of known distance.

1913 - Danish astronomer Ejnar Hertzsprung accurately estimated the distances of a few Cepheids.

This calibration meant that the distances of all Cepheids could be calculated from Henrietta's period-luminosity relation.

Astronomers could now measure the distance from Earth to any visible Cepheid star in the universe.

The steps used are:

- Identify the star as a Cepheid variable by studying its spectrum (if possible) and/or by the shape of its light curve.
- Measure its period and apparent magnitude.
- Use the Period-Luminosity relation to determine the absolute magnitude.
- Use the inverse-square law to calculate the distance to the star.

Before Henrietta's research, astronomers could only measure accurate star distances within 100 light-years of us.

Afterwards, they had the ability to measure objects up to 10 million light years away.

Edwin Hubble used Cepheids to measure the distance to the Andromeda "nebula"(1923)

. . . and the expansion of the universe (1929).

Pickering did not allow Henrietta to follow up on her revolutionary discovery.

He assigned her to continue work on his project to standardize magnitudes.

Colleagues remembered her as "possessing the best mind at the Observatory," and "the most brilliant woman at Harvard."

Henrietta worked at the Harvard College Observatory until her death from cancer in 1921.

Her death was viewed as a "near calamity" by her colleagues

Her name was given to a crater of the moon to honor deaf men and women who have worked as astronomers.

11. Sun's spectrum shows lines of iron, silicon, calcium, hydrogen, magnesium, sodium ... Calcium lines are strongest - a calcium sun?

12. What are stars made of?

Cecilia Payne-Gaposchkin (1900 - 1979)

On February 11, 2002, a portrait of astronomer Cecilia Payne-Gaposchkin was unveiled on the wall of the Faculty Room in University Hall, where males greatly predominate.

Born Cecilia Payne in Wendover, England.

When Cecilia Payne-Gaposchkin was five years old, she saw a meteor:
"One winter evening my Mother was wheeling me in my pram, and we saw a brilliant meteorite blaze across the sky. . . She . . . taught me the right name for it by making a little rhyme: As we were walking home that night/ We saw a shining meteorite. It was my first encounter with astronomy."

1919 - at Newham College at Cambridge - became even more interested in astronomy after hearing a lecture by Professor Eddington about his eclipse expedition to Brazil.

Four years later, she received her bachelors degree from Cambridge.

Concerned about the future for women in astronomy careers in England.

Went to the United States for graduate work, where she thought a woman might be more accepted.

Offered a Pickering fellowship (established for women students) by Harlow Shapley (the new directory of the Harvard Observatory).

Cecilia was given Henrietta Swan Leavitt's old desk.

Her dissertation, entitled "Stellar Atmospheres, A Contribution to the Observational Study of High Temperature in the Reversing Layers of Stars."

Showed that the great variation in stellar absorption lines was due to different amounts of atomic excitation and ionization (different **temperatures**), not different abundances of elements.

She correctly concluded that silicon, carbon, and other common metals seen in the sun were found in about the same relative amounts as on Earth - but the helium and particularly hydrogen were vastly more abundant (by about a factor of one million for hydrogen).

This result disagreed with earlier theories - when she sent a draft of her paper to Henry Norris Russell, he replied that such a result was "clearly impossible."

Russell had an earlier paper which argued that, if the earth's crust were heated to the temperature of the sun, the spectrum would look the same.

Deferring to Russell's stature as an astronomer, Cecilia added the comment that her results were "almost certainly not real."

Within a few short years most other astronomers had come around to believe that hydrogen was far more abundant in the Sun than in Earth.

Otto Struve described this work as "the most brilliant Ph.D. thesis ever written in astronomy."

1932 - Cecilia went to Berlin for the meeting of the Astronomische Gesellschaft.

There met a young Russian astronomer Sergei Gaposchkin and heard his plight as a Russian astronomer in Nazi Germany.

Helped him get out of Europe - found him a position at Harvard.

1934 - Sergei and Cecilia were married.

Cecilia collaborated with her husband.

She was interested in variable stars, he was interested in eclipsing stars. Cecilia wrote:
"When we come to an eclipsing star, I would say to my husband, 'That is yours.'
And when we would come to a pulsating star, I would say, 'That is mine.'"

1936 - finally given a formal position (as an "astronomer") by Harvard.

1956 - made a full professor and chair of the Astronomy Department - the first woman to hold either position.

Cecilia was working before nuclear physics started, before the nature of external galaxies was recognized, and before the interstellar medium was discovered.

By the end of her life she was using ultraviolet data from a satellite. Atomic physics flowered around her.

Always did very timely, very new work.

1977 - received the Henry Norris Russell Prize from the American Astronomical Society.

The following is an excerpt from acceptance speech and memorial lecture for the Russell prize:
The reward of the young scientist is the emotional thrill of being the first person in the history of the world to see something or to understand something. Nothing can compare with that experience . . . . The reward of the old scientist is the sense of having seen a vague sketch grow into a masterly landscape. . . . The old scientist cannot claim that the masterpiece is his own work. He may have roughed out part of the design, laid on a few strokes, but he has learned to accept the discoveries of others with the same delight that he experienced his own when he was young.

13. What have astronomers actually been looking at?

Vera Rubin (1928 -)

"I was about ten years old . . . and had a very small bedroom with a bed right under the window which faced north. When I would go to sleep at night I would look at the stars and I would watch the stars move as the Earth turned and I just got very interested in the movement that took place in the sky."

1947 - requested a catalog of Princeton's graduate program.

Was told that Princeton did not accept women in the graduate physics and astronomy programs.

At Princeton: 1971 - first women admitted to graduate physics; 1975 - first women admitted to graduate astronomy; 1976 - first women admitted to graduate math.

1948 - B.A. at Vassar (Vassar granted her a needed scholarship)

Three years later she got her M.A. at Cornell - Vera had gotten married and her husband (a physicist) was doing his Ph.D. there.

Husband got a job at Georgetown University. Vera followed and was pregnant with a second child when she entered Georgetown's Ph.D. program.

1954 - Ph.D. (Astronomy) at Georgetown University.

Ten years later, Vera became the first woman permitted to observe at Mt. Palomar.

Historical background - - - - -

1933 - Vera is 5 years old - the first evidence of dark matter was found in clusters of galaxies.

Fritz Zwicky discovered that the mass of luminous material in a cluster of galaxies was much less than the total mass of the cluster implied by the velocities of the galaxies.

Not enough luminous mass for its gravity to keep the galaxies from flying apart.

End of historical background - - - - -

1978 - Vera conducts a study on the rotation of galaxies using a radio telescope.

If you look at a spiral galaxy edge-on, some stars will be moving toward you and some will be moving away because of the rotation of the disk.

Their spectral lines will be Doppler shifted to an amount determined by their speed.

By plotting the velocity (calculated from the Doppler shift) against the distance from the galactic center, a rotation curve can be constructed.

Vera found that a large portion of the graph was flat; the stars near the edge of the galaxy were moving at the same speed as stars in the middle - not like our solar system and not what she expected.

There must be some unseen matter pulling on the stars with its gravity, causing the stars in the galaxy to orbit faster that expected.

Vera wrote:
"Most of the matter in the universe is not radiating at any wavelength that we can observe. At least 90 percent of the matter in the universe is dark. And that is a rather daunting idea. We became astronomers thinking we were studying the universe, and now we learn that we are just studying the 5 or 10 percent that is luminous."

Today Vera is a Staff Scientist at the Carnagie Institution - works at the Department of Terrestrial Magnetism in Northwest Washington.

Studies galactic and extragalactic dynamics; large-scale structure and dynamics of the universe

A celebratory symposium honoring Vera Rubin was held this January 2002.

Vera writes:

I live and work with three basic assumptions:

1. There is no problem in science that can be solved by a man that cannot be solved by a woman.

2. Worldwide, half of all brains are in women.

3. We all need permission to do science, but, for reasons that are deeply ingrained in history, this permission is more often given to men than to women.

14. How are we doing today?

AAS stats show women are still under-represented.

What is "fully represented?" For both men and women: When every person who wants to become an astronomers receives the full support and encouragement he or she needs to succeed.

What can we do?

15. Vera's answer applies to both young men and women.

Get the fun and excitement of doing science across to the young. Stress that science requires imagination, creativity, and ardor. [Amateur astronomers!]

Provide children with positive role models early on, both in the home and at school. [Amateur astronomers!] (This also requires teacher training to dispel stereotypes and reduce science phobia.)

Nurture everyone who enters college wanting to be a scientist. Welcome them to science.

Recognize the value for science of talents other than problem-solving. Among the most important criteria for achievement are creativity in devising programs for study, ability to see connections, a good memory, perseverance, and lots of energy.

Give young students the self-confidence to believe they can be scientists. Achievement is tied to expectation.

16. A final word from Vera Rubin:

"It seems to me that our forefathers and foremothers were perhaps luckier than we are because they lived outside enough to be much more familiar with the sky than are most people today. And I think that if somehow we could get the public to go on a very dark night out into the country and to look at the Milky Way, most of the children would be overwhelmed. When I talk to elementary school and junior high children, I very often begin by asking them if they have ever seen the Milky Way. And the answer in universally no. If we [could] . . . get people to drive 60 miles from their city out into the country and just spend a few hours in the early evening looking at the Milky Way, they could understand that they are looking at our galaxy. That the brightest part of the Milky Way that they are seeing in the south is toward the center of our galaxy. And I think we could increase not only their awareness, but their interest in science. People would see that these views are really spectacular." - Vera Rubin

This what you do every time you host a public star party and show people the moon, planets, stars, nebula, galaxies, and the Milky Way.

It has been a pleasure talking to a group of people who share their excitement and make the skies available to everyone, male and female, young and old. Thank you, and keep up the good work!