VI. LAST WORDS

ASTRONOMIZING AT ST ScI

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Q: How many psychiatrists does it take to change a light bulb?
A: It only takes one, but the light bulb has to really want to change.

My favorite light bulb joke sums up the state of affairs in astronomy today—I want to work in a field that includes me, but that requires a change in the field. The change may not be hard to make, but it requires will on the part of myself and the other people who want to make the field more inclusive.

Tonight I am going to start by telling a few stories from my career in astronomy, starting as an undergraduate student at the University of Wisconsin up until the present time. Then I will tell you about some of results found with the Hubble Space Telescope.

My knees always used to shake when I entered the physics and astronomy buildings at the University of Wisconsin. The halls had the feeling of a men's locker room. In the early 1970's, when I was a student there, the physics and astronomy departments had no female faculty, and as far as I know had never hired a female faculty member. Every office had a man behind the door; the only women present were secretaries. With a dry mouth and a rapidly beating heart, I went one day to a meeting with my undergraduate astronomy advisor. After knocking on the door, I walked into the room and before I was invited to sit down, he looked at me and said "I guess we are not going to have to worry about the draft." I was speechless, so by way of explanation he continued "For all the other students, we have to worry about the draft." That was the content of the guidance I received from my advisor and pretty much summarizes the mentoring that I received as a student.

The next year, when I was a junior majoring in astronomy/physics at UW, we were assigned a text in thermodynamics. The inside cover of the text has a series of pictures of the people who had contributed to the field in its illustrious past. There, assembled on one page was a manifestation of my unformed thoughts about myself and the field that I was dead-set on studying. The thoughts manifested themselves as beards, mustaches, side burns, and bald heads. With the hair on the bottom of their faces instead of the top, the physicists all looked upside down. I felt upside down in a field that admitted no precedence for me.

I suppose that all undergraduate students are quite self conscious, and that a physics department is intimidating for male students as well as for female students. But there is an extra element of intimidation that a female student must face when trying to survive in an all-male environment. One day as an undergraduate I wore a skirt to my optics class—a rather elegant, long, hand-woven skirt worn together with a mexican blouse. As I entered my optics class and crossed the room to sit down, forty pairs of male eyes followed me across the room. I felt like an alien life form. Five years went by before I wore a skirt again.

Like a gosling that attaches itself to the first moving object, and gives to it the status of parent, I remember the first name of a living female astronomer that I heard. I was sneaking around the library one day, trying to be inconspicuous, when I discovered a AAS Newsletter on the topic of the Status of Women in Astronomy. It was remarkable to me that this was a topic, since I didn't realize there WERE any women in astronomy. The article stated that the percentage of women in the field had been falling steadily since World War II. I then looked at the header of the newsletter and found that the president of the AAS was someone by the name of Margaret Burbidge. Reading her name was like being struck by lightening. If I had never heard that name, I am not sure that I would be in the field today. The name Margaret Burbidge was the light at the end of a very long, dark tunnel for me.

After graduating from UW, I moved to Copenhagen and picked up my studies in physics and astronomy at the Niels Bohr Institute and the Copenhagen Observatory. Although the female/male ratio was no better in Denmark, I found it easier to be a student there than in the states. The relations between the sexes are more relaxed in Denmark, so that I never felt like an oddity in class. For the first time, I had fellow students to study and discuss material with. For the first time, I was an active participant in class, asking questions and engaging in discussion without undue self-consciousness. For the only time in my years as a student, I had female professors. In retrospect, there was one other factor that made student life in science easier for me in Copenhagen; my strangeness as a foreigner upstaged my strangeness as a female.

After studying in Copenhagen, I returned to the United States and studied at New York University—another all-male physics department that has never in its history hired a female faculty member. I also attended my first AAS meeting at Rensselaer Polytechnic Institute. There I saw something rare and beautiful. Suddenly in the extra-galactic session, a woman in a blue blazer and flowered skirt stood up and proceeded to give an excellent talk on starburst galaxies. The ten-minute talk by Vicki Balzano was the first talk on astronomical research I had ever heard by a women.

I also gave my first poster at that meeting. A senior astronomer from Harvard, who I had not met before and who was not in my field, was terribly interested in my poster. He discussed my poster and a number of other topics with me in depth, but without ever looking me in the eyes. His gaze was directed instead to what I call a woman's second set of eyes. Since the second set of eyes are set rather widely apart, he had to turn his head to see them both. The whole time I was talking with him, he resembled a windshield wiper. At subsequent AAS meetings I discovered that the windshield wiper effect was common when I engaged in discussions with male colleagues, especially senior male colleagues. I tried to combat the effect by fixing my gaze at what the french call a man's *petite tête* (*i.e.,* the *petite tête* rules over the *gros tête*). But none of my male colleagues got the hint. Meanwhile, I got very little out of interactions with many of my colleagues.

Graduating and getting a post-doctoral position was like going from the frying pan into the fire. I discovered quickly that dressing in a feminine manner brought an enormous amount of unwanted attention. I have heard male colleagues complain that women get more attention than men in the field so that it is easier for the women. What people don't seem to realize is that the attention is destructive. Being a women in astronomy is like having bad parents—it takes you longer to grow up because of the bad and inappropriate attention that you receive.

When I realized that my dress was a problem, I went into what Rosie Wyse refers to as "the black chador" phase. Women in arab countries don a black chador when they go into the outside (*i.e.,* male) world. But there are many ways to don a black chador. My black chador consisted of blue jeans and plaid shirts.

When I moved to a tenure track position at ST ScI, I was the only woman in a tenured/tenure track position. Before my first annual review with the Director, I asked colleagues what to expect, so that I could prepare for it. I was told that Riccardo Giacconi always asks what your long term goals are. On thinking about it I realized that I did not have, and indeed had never had anything like a long term goal. The Institutes I had been at had no senior women, so I made the implicit assumption that I would fail soon. It seemed unlikely to me that I was much smarter, much harder working, much better connected, or much luckier than all the women who had failed before so. So why bother with a long term plan?

I would like to conclude this part of the talk with three lists and a few lines from Walt Whitman's early edition of *Leaves of Grass*.

The two tough things about being a woman in astronomy are:

1. You can't make a female astronomer out of an all-male template.
2. You can't concentrate on astronomy when someone is staring at your second set of eyes.

The two sentences that I most hate to hear from male colleagues (what I call my "Thelma and Louise" list) are:

1. "She wears provocative clothing." In the 20 years that I have been in astronomy, I have never heard the statement, "He wears provocative clothing," yet I know astronomers who wear tight blue jeans. From this I conclude that what is provocative is not the clothing that women wear, it is the body under the clothing. I do wish that men in the field would get used to it! All women have two sets of eyes, but only one set concerns anyone during work. I believe that men are responsible for their actions, regardless of the attire of women around them.
2. "She got my job." My only answer to that statement is, "He's gotten my job for a thousand years."

The six things that have made ST ScI a place that I want to stay at, a place that I feel commitment to, and a place that I think I will have a productive, successful, and satisfying career at are:

1. Meg Urry was hired into an ST tenure track job about a year after me.
2. Laura Danly decided to take her Hubble Fellow at ST ScI.
3. Stefi Baum was hired into an ST tenure track position about 2 years after me.
4. Melissa McGrath was hired into an ST tenure track position.
5. Anuradha Koratkar was hired into an ST tenure track position.
6. Patricia Vader was hired into an ST tenure track position.

From *Leaves of Grass*, July 1855, by Walt Whitman:

> I know I have the best of space and time—and that I was never measured, and never will be measured.

2. SCIENCE WITH HUBBLE SPACE TELESCOPE

A meeting on the status of women in astronomy would not be complete without some discussion of the science that interests us all so. I will discuss three results from HST that span a large range of scientific topics and demonstrate very different capabilities of the telescope. First I will discuss a topic that involves the most distant and luminous objects in the universe. The intervening absorption line systems that are detected in quasars allow us to view the universe at great distances. Then, I will discuss Vela X-1, the binary X-ray star whose history reads like a history of the space program, with each new rocket and new satellite adding a clue to the puzzle. Finally I will discuss something really local: the HST study of the storm on Saturn.

2.1. Absorption Line Systems in Quasars

Quasars, first discovered in the 1960's, were first referred to as "radio stars."[1] But they were soon found to be the most distant and luminous objects available to astronomers, and as such provide a means to observe the distant, early universe. Through detection of the Lyman alpha and metal line absorption systems produced by intervening material, and measurement of the observed wavelengths and the strengths of the lines, we can calculate the number and the size of the gas clouds at distances out to the quasars.

Before the advent of HST, these absorption systems could be observed with high signal-to-noise ratio only at redshifts greater than about 2 because the most common absorbers (Lyα 1216, CIV 1550, and MgII 2800) lie in the ultraviolet and must be redshifted to be observable from ground based telescopes. Absorption systems at redshifts greater than 2 show evidence for two different populations of absorbers; those with heavy elements and those without. The populations differ in their velocity dispersions, their clustering properties, and their apparent sizes. The absorption lines that contain heavy elements have velocity widths of about 150 km/s, show some clustering for velocities of less than 500 km/s, show little or no evolution, and correspond to clouds with sizes between 0.003 and 300 kpc. The Lyman alpha forest lines, are not associated with systems with associated heavy element lines, have velocity widths of about 25 km/s, show no evidence for clustering, show considerable evidence of evolution, and are formed in clouds with sizes between 0.4 and 400 kpc.

This year a great deal of research has concentrated on characterizing the absorption systems at redshifts lower than 2, the redshift region observable with HST. A number of different studies seem to be pointing towards similar conclusions; that some of the absorption systems detected with HST are consistent with absorption by galaxies. This result is in apparent contradiction with ground-based studies of $z > 2$ absorption systems. The higher redshift absorption Lyman alpha systems have not been observed to be clustered and therefore have not been thought to be associated with galaxies.[2]

One of the most interesting and important results from the first year of observations with HST is the discovery that the evolution of the Lyman alpha forest absorption systems seems to stop at about a redshift of 2.0.[3,4] Among the first results from the key project on quasar absorption lines[5,6] is the verification of the lack of evolution as reported by Bahcall and Morris in 1991.

The first observational report of the absorption line key project involves about half of the total sample of data for cycle 1, or 36 objects.[5,6] The quasars have been observed with the Faint Object Spectrograph using the high resolution gratings centered on the wavelengths 1300Å, 1900Å, and 2700Å. The spectra have been searched algorithmically for Lyman alpha systems. The number of Lyman alpha clouds as a function of redshift can be expressed as

$$dN/dz = (dN/dz)_0 * (1+z)^{\gamma}.$$

Bahcall *et al.*[5] find that when only the low-redshift data are included in the evaluation, the redshift distribution (with large uncertainty) can be given by

$$dN/dz = (dN/dz)_0 * (1+z)^{0.3}$$

(see Table 9 in Bahcall *et al.*[5]). The value for gamma goes up considerably if ground based data, *i.e.,* higher redshift data, are included in the analysis. Either the evolution of the Lyman alpha clouds changes considerably at redshifts of about 2, or the clouds at low redshift represent a different population than the clouds at high ($z > 2$) redshift.

The clustering properties of the Lyman alpha clouds are of great interest since they may help identify the origin of the absorbing clouds. The two-point correlation function was calculated for the key project data based on relative velocities between all pairs. Although the two-point correlation function shows no evidence for clustering, Bahcall *et al.*[5] emphasize that approximately three times as much data are required to differentiate between clustering consistent with galaxy clustering and lack of clustering.

In spite of the inconclusive results regarding clustering, which would link the Lyman alpha absorption systems to galaxy systems, a number of observations of individual objects give examples of both clustering in the absorption lines of individual quasars, and examples of detections of absorption lines typical of high-redshift absorption lines, at the same redshift as known intervening galaxies.

The first example is that of the absorption systems detected in the quasar H1821+643. Ultraviolet spectra taken with the FOS with resolution of 1.1–2.0 Å show a number of complex absorption features, some of which are coincident with the quasar's emission lines.[7] The intervening absorption features seem to show evidence of correlation on scales on which galaxy correlations have been measured. A statistical test using Monte Carlo simulations was performed to evaluate the significance of the correlations. The correlations of the absorption lines detected in H1821+643 were found to occur in only 4% of the simulated spectra, implying that the correlations are not likely to be a random effect.

As mentioned above, H1821+643 also shows absorption close to the emission line center: so-called associated absorption. Since H1821+643 is radio-quiet, its associated absorption does not fulfill the suggested relation between radio emission and associated absorption.[8] However, imaging[9] and follow-up spectroscopy[10] show that H1821+643 resides in a rich cluster of galaxies. The cluster members may be the cause of the associated absorption in H1821+643.

Observations of 0405–123 provide a counter example to H1821+643.[11] Like H1821+643, 0405-123 is thought to reside in a rich cluster of galaxies.[12] Yet unlike H1821+643, the UV spectra taken with FOS yield no associated absorption lines. It seems that residence in a rich cluster may be a necessary but not sufficient requirement for the presence of associated absorption.

Two studies of the absorption lines of Mrk205, one with the FOS[13] and one with the GHRS[14] report the first detections of absorption due to the intervening galaxy NGC4319. Such observations are important as a means of identifying the origin of high-redshift absorption systems by comparison with systems known to originate in galaxies. Both studies detect Galactic absorption in addition to absorption from NGC4319.

With the high-resolution spectra of the GHRS, Bowen and Blades report that, while they see only one simple MgII 2800 Å absorption feature from NGC4319, many MgII components are detected from the Milky Way, with a large velocity span of about 100 km/s. The interstellar medium in NGC4319 appears considerably more ionized than that of the Milky Way, based on the presence of the CIV absorption, in spite of the weakness of 21 cm emission from HI.

However, the most important question addressed by the absorption line spectrum of Mrk205 is: How do the ultraviolet absorption lines at high redshift compare with the absorption caused by neighborhood galaxies and with absorption caused by the Milky Way? In comparing the detected MgII equivalent width (EW) due to NGC4319 and due to the Milky Way with the distribution in EW as a function of redshift discussed by Steidel & Sargent,[15] Bowen and Blades find that the two examples lie on the extremes of the distribution. While the MgII absorption feature due to NGC4319 is at the weak end of the distribution, the MgII feature due to the Milky Way is unusually strong for a low redshift (sic) line when compared with the Steidel and Sargent absorption features (with average redshift of 1.12). The authors argue that, although the Milky Way MgII EW is large, it is consistent with the strongest MgII systems observed at redshifts greater than 1, suggesting that such absorption does indeed arise in the disks of galaxies.

In summation, the latest work with quasar absorption lines strengthens the conclusion that the Lyman alpha cloud systems show no evolution below a redshift of 2.0. There is some evidence for clustering, implying that the Lyman alpha clouds may be made up of a different population at low redshift than at high redshift. The quasars H1821+643 and 0405–123 provide an interesting comparison since they both appear to lie in rich clusters and yet only one of them (H1821+643) shows absorption at the redshift of the host cluster. Thus membership in a cluster may be a necessary but not sufficient condition for associated absorption. Finally, observations of the quasar-galaxy pair Mrk205 and NGC4319 show that both nearby galaxies and the Milky Way can cause absorption features similar to those observed at high redshifts. The quasar-galaxy pair also demonstrates that there is a large range of properties of those absorption features in the strength of the feature, the velocity dispersion of the feature, and the ionization level present, even for low-redshift (*i.e.,* NGC4319 and the Milky Way) galaxies.

2.2. Vela X-1

The discovery and understanding of Vela X-1 is closely linked with the development of space observations—from the first discovery from rocket observations, to increasingly more sophisticated satellite experiments, to the very detailed picture of variability in this system from the latest HST results.[16]

The first discovery of X-ray emission from Vela X-1 was made with rocket observations in 1966.[17] After the initial discovery, observations with the OSO-7 satellite[18] showed that Vela X-1 was an eclipsing binary source with an orbital period of 8.96

days. The UHURU X-ray satellite gave an accurate sky position for Vela X-1 enabling Hiltner[19] to identify its companion as the hot supergiant star HD77581. The X-ray satellite SAS-3 found that the X-ray signals from Vela X-1 pulsate with period of 283.33 s.[20] We know that the Vela X-1 system consists of a neutron star orbiting a hot (B0.5Ib) star. Some of the gas from the extended atmosphere of the supergiant companion falls onto the neutron star, and the tremendous gravitational energy of the infalling material is turned to heat when the gas strikes the neutron star surface, and radiated as X-rays. Strong magnetic fields at the neutron star surface collimate the X-rays into beams that rotate with the 283.33 s spin period of the neutron star.

An OB supergiant star like HD77581 normally loses mass in a strong stellar wind. Evidence for winds in many such stars has been seen by the Copernicus and IUE satellites. P-Cygni profiles of resonance lines such as CIV$\lambda\lambda$1548,1551, SiIV$\lambda\lambda$1394,1403, and NV$\lambda\lambda$1239,1243, consisting of a blue-shifted absorption line and a redshifted emission line. The stellar wind in front of the star acts as a blocking filter in the blue-shifted part of these lines, scattering stellar continuum photons out of the beam to the observer. The X-ray beam increases the ionization level of elements in the wind, changing the abundance of the ions responsible for the resonance lines, thus modulating the optical depth of the blocking filter. A prediction by Hatchett and McCray[21] that this effect would result in modulation of the P-Cygni lines with the X-ray orbital period was confirmed by observations with the IUE satellite.[22]

Kallman, McCray and Voit[23] then theorized that the rotating X-ray beam sweeping through the stellar wind should cause the abundances of certain ions to vary with the 283.33 s pulsation period—and that variation would yield direct information about the structure and ionization level of a stellar wind with X-ray emission incident upon it. To test this theory, McCray proposed to take spectra with the FOS in the G130H grating to monitor the CIV$\lambda\lambda$1548.19, 1550.76, SiIV$\lambda\lambda$1393.75, 1402.77, and the NV$\lambda\lambda$1238.81, 1242.80 lines every 20 seconds. Simultaneous observations were taken with the Ginga X-ray satellite[24] so that an observations of pulsations in the UV spectral features could be correlated with the X-ray behavior.

The FOS spectral data were binned to increase the signal-to-noise ratio, and the spectral bins were analyzed for the presence of pulsations. Although many trial periods were investigated, the only periods with evidence of pulsations were the pulsar period (283.33) and half the pulsar period. The red component of the SiIV absorption doublet (1402.77) pulses at 283.33 s, and the NV absorption doublet pulses with most power at the 283.33/2 s harmonic. When correlated with the X-ray data, the SiIV absorption line is seen to increase with increasing X-ray intensity (with a 15 s phase delay), while the NV absorption doublet decreases with increasing X-ray intensity. Although these observations do agree generally with the prediction of Kallman, McCray, and Voit[23] the lines that pulsate are different than predicted and the amplitude of pulsation is different. (CIV was predicted to pulse with a 30% change in amplitude, while SiIV and NV were observed to pulse with a 3% change in amplitude.) The differences between theory and observation relate to how far into the stellar wind the X-rays penetrate, and what the shape and orientation of the X-ray beam is relative to the stellar envelope. Also, while X-ray illumination decreases the amount of SiIV, thus decreasing the strength of the SiIV absorption feature, the X-ray illumination increases the amount of NV briefly. Apparently, the X-ray beam reduces the abundance of SiIV in the wind, thus reducing the opacity of the SiIV absorption line. In contrast, the X-ray beam increases the abundance of NV in the wind, thus increasing the opacity of the NV absorption line. Thus, there is an anticorrelation between NV absorption and X-ray illumination.

The HST observations of Vela X-1 reported by Boroson *et al.* open a new line of detailed investigation into binary pulsars. Further analysis, especially into the phase lags between the X-ray and the UV lines may be very fruitful in mapping the shape of the X-ray beam and the dynamics of the stellar wind.

2.3. Saturn Storm

On September 25, 1990, a bright white spot was sighted on Saturn by S. Wilber, M. Sweetman, and A. Montalvo[25] (IAU Circular 5105, 28 September, 1990). This spot was subsequently observed to be a storm that was expanding rapidly towards the east. Two previous storms of this magnitude have been reported on Saturn; in 1933 and in 1876. These storms are spaced by 57 years, or two Saturn years. When plotted against Saturn season, it is apparent that each storm occurred during the northern hemisphere summer on Saturn.[25]

The ground-based observations were used to predict the location of the storm for November 9–18, 1990, when an extensive Target of Opportunity program was begun to observe the Saturn storm.[26] Eventually, three data sets were taken that span the start of the storm, the development of the storm as it spread across the east/west zonal band of the planet, and finally the dispersal of the storm. The entire storm seems to have developed from a single eruption in late September 1990, and within two months, to have distributed itself more or less evenly in one zonal band around the planet. This data set gives an anatomy of a planetary storm such as has never been seen before.

Saturn, like the Earth, has a delay between solar zenith angle and actual conditions on the planet. However, Saturn's delay is more exaggerated than that of Earth, with a thermal response thought to lag by one full season. Thus, during the northern hemisphere summer on Saturn, the top layer of the atmosphere is thought to be cooling. Since the lower layer remains hot, the atmosphere becomes unstable to convection, causing the Great White Spot. One aspect of the Saturn storm that is interesting and difficult to understand is that, in contrast to all other radiative processes on Saturn, which are sluggish, the storm is apparently an eruptive event that proceeds very rapidly. Beebe *et al.*[25] speculate that there may be synchronous events that cause the storm to erupt, such as an instability in the cloud forming regions that is in phase with insolation changes tied to a multiple of the Saturn year.

The most spectacular data set among these three is the sequence of images taken in November 1990, which cover two consecutive orbits. From each image of the planetary disk, a cat's eye was taken and projected onto a square surface. The consecutive squares were lined up and merged, and then projected back onto a sphere. As the planet turns, the entire surface rotates into view and the storm is seen to progress across the central zonal band of the planet. The storm develops in three phases. The initial (explosive) convective disturbance is followed by an east/west expansion. During the phase of expansion, the eastward progression of the storm produces large scale wave structures, while the westward progression produces smaller scale structures. There is also evidence of vertical shear in the zonal winds, which indicate an interaction between the storm nucleus and the local wind field.[27] Finally, a planetary scale wave pattern is set up which was tracked as it traversed the planet almost five times.

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