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A Stellar Life

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Abstract

In this autobiography of 70+ yr of publishing astronomical papers, I summarize some of my major fields of research, such as (1) hfs in the solar spectrum, (2) the atmospheres of supergiants, (3) shock waves in Cepheids, (4) the Crab Nebula, (5) frequencies of binaries, (6) exoplanets, (7) starting Kitt Peak National Observatory, (8) catalogs, (9) China, (10) editing the Astrophysical Journal, (11) blue stragglers, (12) the Local Interstellar Bubble, and (13) publication studies.

Key words: biographies – stars: general – ISM: supernova remnants

1. Student Papers

The first paper that I published as a student at Caltech was on the hyperfine structure (hfs) of lines in the solar spectrum (Abt 1952). Hfs is a splitting of lines due to nuclear spin. It does not depend of external effects, such as temperatures, pressures, or magnetic fields. The effect is small (~0.1 Å), only visible with high spectral resolution, and is of the order of isotope splitting. However, this broadening affects line equivalent widths and hence abundance determinations. The splittings have not been calculated for complex atoms, so we have to depend on laboratory measurements.

As a student I tried to get higher-resolution spectra than in the Utrecht atlas, using the 150-foot solar telescope on Mt. Wilson but failed to get a better resolution, so I used the Utrecht atlas. For lines of Mn I, V I, Co I, and Cu I the measured line widths agreed with those from the available hyperfine patterns. The radial velocities of the solar lines differed depending on the shape of their hfs patterns.

At Caltech in 1948 I had an assistantship which paid tuition and $100 per month to work 20 hours/week for a Mt. Wilson astronomer. In my case, it was Olin C. Wilson. He had obtained 100 inch (2.5 m) coudé spectra of the eclipsing binary zeta Aurigae during ingress and egress of the 1947–48 eclipse. That

Helmut at ages 30 and 90 years.

system, seen edge-on, has a supergiant K-type primary that orbits with a B main-sequence star every 972 days. During ingress and egress the light from the B star shines through the thin outer chromosphere of the K star for about a week. In the near-ultraviolet the spectrum of the hot B star dominates over the spectrum of the cool K star. Thus during those times one can sample the ionization of the elements, abundances, temperatures, pressures, turbulence, and radial velocities in the chromosphere of the K-star. It seems amazing that a supergiant has such an extended transparent atmosphere (Wilson & Abt 1951).

However, the most surprising result was that atoms in the transparent chromosphere of the K star are not completely ionized by the hot B star's radiation, even though we know that the ultraviolet radiation from the B star is getting through. Olin Wilson calculated that could be true only if the material in the outer layers consisted of dense clumps, rather than a smooth distribution of material. The clumps are $\sim 10^3$ km in diameter with a density of $10^{13.8}$ hydrogen atoms per cm^3. That presents a very different picture of the outer layers of supergiants. Such clumps are of planetary size but much lower in density.

For a Ph.D. thesis at Caltech I studied the spectra of W Virginis, a Population II (Pop. II) Cepheid with a period of 17.3 days. Sanford (1952) found that the spectral lines are double at times. In addition to Sanford's 13 spectra, I obtained 10 coudé spectra with the Mt. Wilson 100 inch (2.5 m) spectrograph. Each was an all-night exposure. They exhibited double lines of the metals and double emission lines of hydrogen during phases 0.6–1.1. The lines featured weak shortward components at phase 0.6 that strengthened and moved longward while the longward components faded out by 1.1. What caused that doubling?

I received some poor advice, but the real explanation is that the pulsation wave becomes supersonic below the atmosphere because Pop. II Cepheid's have lower masses ($\sim$1 solar mass) and therefore lower surface gravities than Population I (Pop. I) Cepheids. As it moves outward, the shock front causes shortward lines that gradually replace the longward lines from the in-falling material. This happens in the outer 35×10^6 km of the atmosphere. I obtained abundances, temperatures, pressures, and turbulent velocities of the material behind and in front of the shock fronts (Abt 1954). This is a rare astronomical case where one can sample the material in front of a shock wave, in the shock front, and the material behind the shock front.

Later in a post-doc position at the Lick Observatory in 1952–53 I found (Abt 1955) that several RV Tauri variables (R Sct, AC Her, and U Mon) also show double lines. Those Pop. II stars are to the right of the Cepheid strip in an Hertzsprung–Russell (HR) diagram. For example, U Mon has a mean period of 47 days and displacement of 55×10^6 km. Again, I obtained excitation temperatures, ionizations, Fe abundances, and effective gravities at each phase in front of and behind the shock fronts.

2. Early Years

Backtracking, I was born on 1925 May 26 in Helmstedt, Germany. My father owned a furniture factory, which he lost in the German inflation. The family emigrated to the U.S. in 1927 where my father became a furniture designer. He preferred modern designs in the Bauhaus tradition whereas Americans preferred American colonial style at that time. We lived in Jamestown, New York in 1931–1940, which was the furniture capital of the country because it had skilled Swedish craftsmen when furniture was handcrafted with hardwoods.

However, that was during the American depression when few people could afford to buy furniture. So my family moved to the Chicago area where my father designed baby furniture, which did sell during the depression. He died suddenly on 1940 Dec. 4 from a heart attack. Heart disease runs through the male side of my family. My mother went to secretarial school and became an accountant. My brother Karl (2 yr older) went to Northwestern University and was drafted during WWII. He was trained in German and French to interview German prisoners. His experiences are published in his book "A Few Who Made a Difference". For instance, his team learned from German prisoners voluntarily that Germany was amassing 1 million troops in the Netherlands for a last-ditch stand. They sent that information to Eisenhower's headquarters, who ignored it. Hence the disastrous Battle of the Bulge.

I left high school before graduation and went to Northwestern University so as to be in a university before being drafted. I majored in math and physics because I liked them and they were easy. Immediately, I got a position to grade math papers. I became interested in X-rays and obtained X-ray diffraction images for chemists. Then I taught physics labs and finally tested aircraft rivets during the war.

My M.S. thesis was on hollow-cathode spectroscopy, done under Russell Fisher, who was famous for his part in the ALSOS mission. That mission wondered whether the Germans were working on a nuclear bomb during WWII. They reasoned that if they were, there would be radioactivity in the Rhine River water that drains western Germany. During the Battle of the Bulge, Fisher crawled under bombardment half across a bridge and got samples of the river water. The tests were negative.

While working on an M.S., three of us students in physics convinced Wasley Krogdhal to teach us a course in astrophysics. That convinced me that astrophysics is an application of physics that has the added feature of involving mysterious objects, rather than objects on a laboratory table. I remember my mentor wondering once what a Wolf-Rayet star would look like if we could see one.

3. California Institute of Technology

Caltech did not have an Astronomy Department until 1948 when the Palomar 200 inch (5.1 m) was completed. With Jesse Greenstein as department head and only two other faculty

Figure 1. The petroglyph Miller found on White Mesa evidently showing the Crab Nebula supernova of 1054. Photo by W. C. Miller.

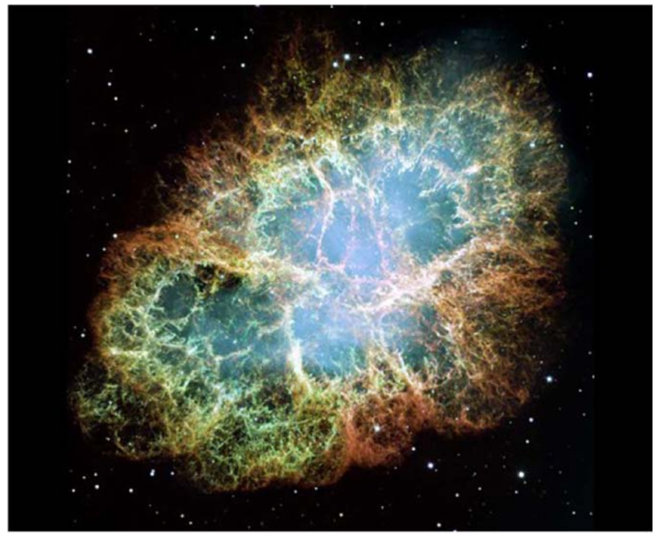

Figure 2. A Hubble picture of the Crab Nebula. The red features are due to Hα radiation from the gaseous filaments. The central blue light is synchrontron radiation coming from the pulsar remnant of the supernova.

members, Greenstein brought in Martin Schwarzschild, Bengt Strömgren, Jan Oort, and others to teach for one quarter each. There were four students the first year: Allan Sandage, myself, and two others who dropped out at the end of the first year. Allan and I found the physics courses to be very difficult, but we decided not to quit unless we were kicked out, which never happened.

Sandage spent his fifth year at Princeton, working with Schwarzschild to produce the first stellar model for a star off the main sequence. After graduation he became the successor to Hubble's position and, among other projects, doubled the size of the universe (the Hubble constant) by noting that the Cepheids Hubble saw with the 2.5 m telescope in nearby galaxies were actually clusters of stars as seen with the 5.1 m telescope. Therefore, after my fourth year, I became the first person to receive a Ph.D. in astronomy at Caltech. I tell people that I graduated at the bottom of my class of one.

I realized that I could not live on $100 a month, but learned of a doctor and his wife in Pasadena who offered a free room and half of the meals in exchange for baby-sitting frequently for their two boys. The whole family became my best lifelong friends. They showed me around southern California and Baja, took me to Hollywood plays, and Flamenco dances.

I loved the southwest. In 1949 I hiked into the Grand Canyon for three days. I hiked to the bottom, camped near the river, and hiked out the third day. During those three days, I

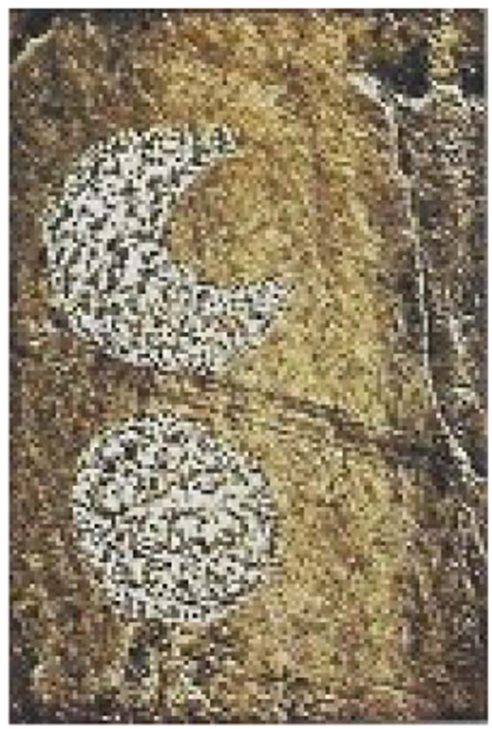

Figure 3. The petroglyph of the Crab Nebula supernova that I found in Navaho Canyon. Photo by the author.

never saw another person except for the mule-driver who brought supplies to the ranch at the bottom. Now the hike is so popular that one has to make reservations weeks in advance. In other trips I hiked alone across the canyon in three days and to Clear Creek, upstream from Bright Angel Creek.

Minor Planet 9423 Abt

Abt 9423 Astronomer
(9423) Abt = 1996 AT7
Discovered 1996 Jan. 12 by Spacewatch at Kitt Peak.
Helmut Abt (b. May 26, 1925) is one of the founders of Kitt Peak National Observatory and is known for his fundamental studies of stellar characteristics, multiple stars and publication practices. As Editor-in-Chief, Abt shepherded the Astrophysical Journal into the current electronic age.

Parameters:

Absolute magnitude: 14.6
Slope parameter: 0.15
Epoch: 2002 May 06
Mean anomaly at the epoch: 304.54432
Argument of perihelion, J2000.0: 329.66446
Longitude of the ascending node, J2000.0: 88.01434
Inclination in degrees, J2000.0: 2.45109
Orbital eccentricity: 0.1749859
Mean daily motion (degrees per day): 0.26607929
Semimajor axis (AU): 2.3940249
Uncertainty parameter: 1
Reference: MPC 32635
Number of observations: 45
Number of oppositions: 5
Year of first observation: 1980

Figure 4. Asteroid Naming Certificate of Minor Planet 9423 Abt.

I became a friend of William C. Miller, the photographer at Mt. Wilson and Palomar Observatory, who developed methods to make photographic plates more sensitive during long exposures and varying color sensitivities. He too loved the region of northern Arizona and southern Utah. For one of many Jeep trips that we took together to that area, he got permission from the Navaho Council to explore the top of White Mesa, which is off limits to non-Navahos. It had not been inhabited since the 13th century. During three weeks we explored on foot the entire 160 km^2 surface and found a natural arch, many potshards showing that the mesa was inhabited during the 11th century, and many petroglyphs. He found one (Figure 1) that showed a round circle and a crescent Moon. Knowing that astronomical objects were rarely shown in petroglyphs, he reasoned that it must have represented a rare astronomical occasion.

Back in Pasadena, Fred Hoyle suggested that it could be a representation of the Crab Nebula supernova (Figure 2), which was first seen on 1054 July 4 according the Chinese records.

It was so bright that it could be seen visually in the daytime for 26 days. With the aid of Brown's tables, Miller computed that on that day the Moon was in a crescent phase and was within 2 degrees of the supernova position, a surprisingly good agreement.

The next summer we explored Navaho Canyon, whose lower region would soon be flooded by the future lake (Lake Powell) behind Glen Canyon Dam under construction. During that trip, I found another similar petroglyph, but reversed (Figure 3). It

Figure 5. In October 2017, Helmut visited and gave a talk in National Astronomical Observatories, Chinese Academy of Sciences (NAOC) and communicated with the audience. His collaborator and friend, Prof. Gang Zhao from NAOC, hosted the talk.

Figure 6. A Chinese stamp honoring Zhang Yuzhe, the long-time Director of the Purple Mountain Observatory.

turns out that the first petroglyph was what would be seen in the spring of 1054 before the supernova disappeared behind the Sun and the second as seen in the summer of 1054. Eventually 31 more such petroglyphs were found by petroglyphs.

Why did the Europeans not record the supernova? Perhaps because of frequent cloudy weather (but not for 26 days!) or a lack of interest in observing the sky during the Dark Ages. However, Collins et al. (1999) conducted a search of European and near eastern ecclesiastical records and found seven records of a new bright star seen between 11 April and 20 May of 1054. Then why did the Chinese not record the bright star in the spring of 1054 and why did the Europeans not record it in the summer of 1054?

We can only surmise the following. In Chinese mythology, a bright "guest" star meant that there would be a new emperor or new dynasty. Probably the Chinese astronomers, fearing for their lives if they told the Emperor and knowing that the guest star would soon disappear behind the Sun, decided to wait a couple months to see if it would disappear before then. However, it did not disappear; they had to tell the Emperor, who died the next year. We do not know what happened to the astronomers.

Then why did the European observers report the bright star in the spring of 1054 but not in the summer? In that year there was a concerted effort to combine the Eastern Orthodox Church with the Roman Catholic Church. On 1054 July 16, they announced that they had failed; it was called "The Eastern Schism". However, there was a bright star overhead that could be seen in the daytime! Was God condemning them for failing? Perhaps they thought it better not to mention the star. However, the Native Americans evidently saw the bright star in both seasons and had no scruples about recording it with petroglyphs.

There are still problems with the Crab Nebula. It was seen near maximum light for 80 days, unlike any other recent supernova.

4. Spectral Classification

I spent most of 1953–59 at the Yerkes Observatory of the University of Chicago. There I learned two-dimensional spectral classification (luminosity versus temperature) under W. W. Morgan. Together we published two spectral atlases

Figure 7. Helmut visited the Potala Palace in 2017.

with grating dispersions. Those succeeded the Morgan, Keenan & Kellman atlas, which was for prismatic spectra. Aden Meinel at Yerkes was designing grating Cassegrain spectrographs that were much faster than previous spectrographs by having large collimator-to-camera focal ratios. Two-dimensional classification, originated by Morgan & Keenan, allowed stars to be placed in HR diagrams and therefore their evolutionary status could be ascertained.

During the subsequent three decades and with the help of students and colleagues, I obtained spectral types, rotational velocities, and radial velocities of the brighter stars in a dozen open clusters and associations. They showed an inverse correlation between duplicity and rotational velocity: single stars (e.g., those in the Pleiades) tend to have large rotational velocities while double stars (e.g., those in the Hyades) have small rotational velocities due to tidal interactions.

For another informative paper, I noted that β Lyrae had visible companions. That is the famous eclipsing binary for which more papers have been published than of any other eclipsing system. Therefore, we (Abt et al. 1962) obtained spectral types, photometry, and astrometric positions to determine the age and masses of the system stars.

5. Supergiant Stars

Among the stars in the upper part of an HR diagram, called supergiants, is the Cepheid strip of stars with single pulsational periods that depend on their luminosities (the period–luminosity relation). That relation has been very useful to determine the distances of galaxies. However, what about the stars to the left and right of the Cepheid strip? Do they pulsate too? I studied a dozen of those with the McDonald Observatory coudé spectrograph and found that all of them are variables and have radial pulsations with multiple periods each (Abt 1957).

Supergiants tend to have very narrow spectral lines. I found with the McDonald spectrograph that in bright giants (luminosity class II) the main source of broadening is rotation but in the brightest supergiants (luminosity class Ia) it is due only to turbulence (Abt 1958).

I found several supergiants to be members of spectroscopic binaries with main-sequence B stars, consistent with our ideas of stellar evolution. Other people found many more such cases.

6. Frequency of Binary Programs

The "metallic-line stars" (Am) are A-type stars that have unusually strong metallic lines, unusually weak helium lines, and normal hydrogen lines for their temperatures. Others noticed that they are often members of binary systems. In a study of 60 Am stars we found that at least 90% have companions (Abt 1961; Abt & Levy 1985). Among the normal stars of the same masses, the frequency is much less (Abt 1965). However, these frequencies make sense because the Am stars have low rotational velocities ($V < 100$ km s^{-1}) while those of the normal A stars have $V > 100$ km s^{-1}. Therefore, if an A star is in a binary with a period less than 100 days, the tidal interaction causes low rotational velocities (in periods <10 days, the rotational and orbital motions are totally synchronized) and they become Am stars whereas single stars retain their original rapid rotation and remain normal stars. This is due to what happens below their atmospheres and the two methods of energy transport: by circulation of the material and by radiation.

A surprise project involved determining the frequency of binaries among high-velocity (Pop. II) and low-velocity Pop. I stars (Abt & Levy 1969). For the latter the distribution of periods peaked at a week and for the former at 100 days. Apparently, while stars form in clusters they pick up companions, which become closer gradually with time. The Pop. I stars stay in open clusters until short-period binaries are formed. The Pop. II stars that are in the galactic disk escaped from globular clusters at an early stage before short-period binaries were formed. That is also why Pop. II stars rarely have exoplanets while Pop. I stars have many.

The most interesting study of binaries was among solar-type stars (Abt & Levy 1976). In a sample of 135 stars, we found that more than half (57%) have stellar companions. Our observational lower mass limit for the companions was 0.2 solar masses. Others (e.g., Michel Mayor in Switzerland) repeated that work with more sensitive equipment and started to find lower-mass companions, or exoplanets, orbiting solar type stars. For that discovery, Mayor received the Nobel Prize.

Figure 8. Helmut was traveling on the train of Qinghai-Tibet Railway in 2017 and made Tibetan friends.

By now, more than 4000 exoplanets have been found. In a sense, the discovery of exoplanets started with Abt & Levy (1976). My studies on binary frequencies among various kinds of stars was summarized in Abt (1983).

There are two ways to produce exoplanets. One is in stellar disks, like in the solar system. The other is that even small (planetary) masses can form as independent objects in open clusters (Tremaine & Dong 2012). Then those small objects may become attached to more-massive stars. The astronomers who have been working on exoplanets assume that all exoplanets were formed in disks. However, the orbital elements of most exoplanets are drastically different from those of solar system planets but very similar to those of double stars. For instance, exoplanets have a large range eccentricities (from zero to 0.99) while all the solar system planets have eccentricities $\leqslant$0.1. Also, most known exoplanets have periods less than a month while all the solar system planets have periods of years. To me this tells us that most of the exoplanets were formed like stars in open clusters, rather than in stellar disks (Abt 2010).

7. Kitt Peak National Observatory

In the 1950s I was a Research Assistant at the Yerkes Observatory of the University of Chicago. The 1950s were the first time that all American cities were connected by commercial air flights. In 1954 John Irwin recommended that there should be a national observatory in the best place in the country for observing by all astronomers in the country. They could fly there in a day and not miss too much teaching time, whereas previously it took up to 4 days each way by train. Robert McMath obtained an NSF grant to search for the best location for astronomy in the continental U.S. and Aden Meinel was selected to head the project. He asked me to do most of the fieldwork.

It was obvious that the site would be a mountain top because the seeing is better there than above Sun-heated plains. Such mountains occur in the southwest U.S. Also, the southwest has the clearest weather. I had aeronautical maps and knew of the mountains above about 2000 m. We arranged for a pilot in Marfa, Texas to fly me in his Cessna 140 for three days around all the candidate peaks so that I could take notes and pictures. He charged me $200 for 2000 miles, or $0.10 per mile for his time, the gas, and the plane. The list of sites was published in my book (Abt 2020) called “A Stellar Life”. In 1955 and 1956 I visited the best sites, either by Jeep, by hiking to the tops and by camping overnight to check for surrounding city lights and nearby smelter smoke, or by going there on horseback. Meinel joined me on a few of those trips.

The five most-promising sites were tested in two ways for two years. (Meanwhile I returned to Yerkes to teach graduate students, such as Jack Brandt, Peter Pesch, Carl Sagan, etc., to oversee Ph.D. theses, and to do research.) One method to test sites was to do photoelectric photometry using 16 inch (0.4 m) Cassegrain telescopes that Meinel designed to fit on car trailers. The other way was to use an instrument designed by Meinel, namely at the top of a 100-foot triple tower, he placed automatic photometers that looked at Polaris through a Ronchi screen as Polaris moved around the pole. If the seeing was perfect, the output would be a rectangular Roman pattern of light and dark; if it was poor, it would be a sine wave. After two years of testing it became obvious that Kitt Peak in Arizona was the best site. I joined the staff in 1959.

In subsequent decades, thousands of astronomers from the U.S. and abroad used the telescopes on Kitt Peak. I helped build and maintain some of the spectrographs, and enjoyed helping astronomers use that equipment. I used those telescopes to study binary frequencies, rotational velocities, and spectral types.

Asteroid 9423, which was discovered in 1996 by Spacewatch at Kitt Peak, was named Abt in 2000 by the Committee on Small Body Nomenclature of the International Astronomical Union (IAU).

8. The George Van Biesbroeck Prize

George Van Biesbroeck was a Belgium astronomer who was invited by Kuiper to work at the University of Arizona because of his work in positional astronomy. Besides work on solar system objects, he specialized in observing astrometric double stars with moderately long periods, ones for which only future astronomers could derive their orbital parameters. He observed until the age of 94. A few of us in Tucson finished his final papers. We also thought after his death that he was an example of an astronomer whose work was primarily for others, rather than for his own reputation. Because all prizes in astronomy were for individual work, we thought there should be an annual one for unselfish work for astronomy. We supported the prize for a decade and then transferred it to the American Astronomical Society (AAS). I did all of the work and (lawyer) expenses of the transfer. Both in Tucson and for the national award a rule was that members of the selection committees were not eligible for the award. Therefore, I was shocked and opposed to being awarded the first national award. However, the AAS Board explained that, after consulting a lawyer, there was a three-day interval between the cancelation of the Tucson award and the start of the national award, so during those three days they awarded it to me!

9. Pacific Islands

I became interested in the Pacific islands at a time when they could be reached by plane in a day, rather than in months by ship. These included Hawaii, Easter Island, the Galapagos, Micronesia, Fiji, Bali, Java, French Polynesia, New Zealand and Australia. A friend and I hiked the length of the Na Pali trail on Kauai in Hawaii. It is one of the most beautiful and dangerous trails in the US. A guide plus porters and we hiked across the uninhabited center of Tahiti in four days. It has mountains, rivers, lakes, and lush vegetation. A guide and I hiked across the center of Viti Levu, the main island of Fiji, in four days. There were villages in the interior but no roads. On Fiji radio each afternoon, the messages were sent to those villages to expect and host two hikers. For more information about some of those islands, please see my book ("A Stellar Life").

10. Catalogs and Indices

Astronomers who study spectroscopic binaries with periods of months or less can obtain their own data, but for longer periods, they have to depend partly on older published radial velocities. To help astronomers search the astronomical literature for each star, we collected all of the published radial velocities in the world in a book entitled "Bibliography of Stellar Radial Velocities" (Abt & Biggs 1972b). I scanned the papers in all known astronomical journals and observatory publications for ones containing stellar radial velocities and Eleanor Biggs transferred the data to IBM cards. Then those data were transferred to a single magnetic tape. That must have been one of the first books ever published from a magnetic tape only. Although heavily used, researchers seldom cite this book, but only the papers on individual stars that they found. Now the Strasbourg Astronomical Data Center maintains that catalog.

Some astronomers, such as R. E. Wilson, were only interested in the mean velocities of stars for galactic structure studies (e.g., galactic rotation) but astronomers working on spectroscopic binaries want to use the individual velocities. Those were available in the files at the Mt. Wilson Observatory in Pasadena. I transferred their times to Julian Dates, corrected the velocities for known systematic errors, computed mean errors, added the spectroscopic dispersions used, and published those for about 24,000 stars (Abt 1970, 1973).

I obtained and published MK types for thousands of visual binaries (Abt 1985a and Abt 2008) and stars in the "Supplement to the Bright Star Catalogue" (Abt 2004).

Before the availability of online searches, we had to depend on Annual and General Indexes of journals to find published papers. The Astrophysical Journal (ApJ) was among the best so indexed. Every five years it came out with a General Index, which I used heavily to search for older papers as I changed fields of research. When one for Volumes 101–125 failed to come, I phoned Editor Chandrasekhar (Figure 9). He said that he was too busy to compile one. Whereas the staff at the University of Chicago Press could compile the Author Index, it took an astronomer to assign papers to various subject headings for the Subject Index. I asked him if I compiled such a manuscript, would he publish it. He readily agreed. Therefore, with the help of Eleanor Biggs we compiled an index for volumes 101–135 (Abt & Biggs 1964). Later he asked me for additional General Indexes, so we did one of Vol. 136–145 (Abt & Biggs 1967) and 146–165 (Abt & Biggs 1972a). After those I was the ApJ Editor and arranged that the subject headings were attached to each published paper.

Once Mrs. Biggs and I had developed the system, we did a General Index for the AJ, 1944–1975 (Abt & Biggs 1979).

11. China

In 1985 there was a joint Chinese-American conference on stellar astrophysics in Beijing. Nine Americans attended by means of an NSF grant arranged by Kam-ching Leung. An international science conference was so rare in China after the Cultural Revolution that the conference was highlighted on the 6 pm evening TV news. The Americans also went to a half dozen other cities and observatories in China.

After the end of the Cultural Revolution, it was realized that the Chinese astronomers were far behind the rest of the world in research. Therefore, they did three things. (1) They sent their best students abroad to get Ph.D.'s in the U.S., England, and other countries. (2) They sent faculty members abroad for the same reason. (3) They invited foreign astronomers to China to give lectures and advise astronomers. I took part in all three. I fostered students and faculty to come to the U.S. In addition, I went to various observatories in China 13 times in 1987–2017 to give lectures. Because I changed fields frequently as shown herein, I always had new fields of astrophysics to discuss. In addition, I helped the Chinese to start their first astrophysical journal in English, which became this journal (RAA, previously called ChJAA).

Chinese culture did not encourage individual initiatives over group initiatives, but in the West, we learned that prizes encourage individuals to do their best work. Therefore, I started and funded an annual prize for the Chinese astronomer who had done some of the best research in the previous five years. The requirement was worded that way so that it was not automatically given to the most senior astronomer. In addition, because relations between China and the U.S. were not great, I named the prize for a Chinese astronomer, namely Zhang Yuzhe. Most Chinese were not aware that the funding came from the U.S.

Later the Chinese Astronomical Society took over the funding. Zhang Yuzhe had gone to the U.S. to get a Ph.D. under George Van Biesbroeck in the University of Chicago and then returned to China in 1929 to become Director for many years of the Purple Mountain Observatory near Nanjing.

I was selected in 2020 for the Chinese Government Friendship Award, the highest award established by the Chinese Government to commend foreign experts who made outstanding contributions to China's modernization. It was officially established in 1991 by the State Administration of Foreign Experts Affairs authorized by the State Council. The award of the gold medal has been postponed because of the COVID-19 ban on travel. As far as I know, I am the first international recipient of the Chinese Government Friendship Award in the field of astronomy.

I grew to like many things about Asia, such as the scenery of Huangshan Mt., the Stone Forest, Emperor Qin Shi Huang's terra cotta army, the area around Lijiang, the Tibetan plateau, and the Li River. Also I like Chinese opera (e.g., Mei Lanfang), Japanese Noh plays (The University of Michigan has published translations of dozens of those plays), Japanese Kabuki, jade carvings, Chinese stamps, Tang Dynasty poetry (e.g., Li Bai, Du Fu, Zhang Ji), Chinese music (e.g., Tan Dun), and Chinese calligraphy. I bought two dozen jade carvings after the Cultural Revolution while they were still cheap.

China had a long history of discoveries, which were unknown to the West until recently. Thanks to the discoveries of Joseph Needham and his associates, we learned about discoveries made by the Chinese 2000 yr earlier than in the West. For instance, the Chinese discovered sunspots, using a pinhole camera, in the 4th century BC whereas the Europeans thought that they were first seen by Galileo in 1612 AD. The Chinese then determined the rotation period of the Sun ($\sim$27 days) and the sunspot cycle of $\sim$13 yr. In the 6th century AD they discovered the existence of the solar wind, from comet tails always pointing away from the Sun, while the West did not discover the solar wind until the 20th century. The Chinese made iron in the 4th century BC and steel in the 2nd century BC, while Europeans discovered steel with the Bessemer process only in 1856 AD. The Chinese drilled wells for salt and natural gas 1.2 km deep in the 1st century BC, using iron bits and bamboo shafts, 2000 yr before the West drilled deep wells.

Examples in medicine included the circulation of blood in the 6th century BC, 1800 yr before the Europeans did that. They recognized deficiency diseases in the 2nd century BC such as beriberi—2100 yr before the Europeans. The people in south China ate rice, which is rich in vitamin B_1, while those in northern China ate wheat. The Chinese recognized diabetes in the seventh century AD from urine.

There are dozens of such inventions and discoveries from 2000 yr ago: see Temple (1986), which is a summary of Needham's work. I gave talks about those early discoveries to Chinese students because many were taught that all important results were made after the Cultural Revolution.

12. The Astrophysical Journal

The ApJ was started in 1895 by George Ellery Hale and published by the University of Chicago Press. The Editor in 1952–1970 was Chandrasekhar who later received the Nobel Prize for his work on white dwarfs. He started the Letters and the Supplements. In December 1970 he surprised me with an offer to succeed him as Editor. I said that I did not know astrophysics as well as he did, but he replied that the coming

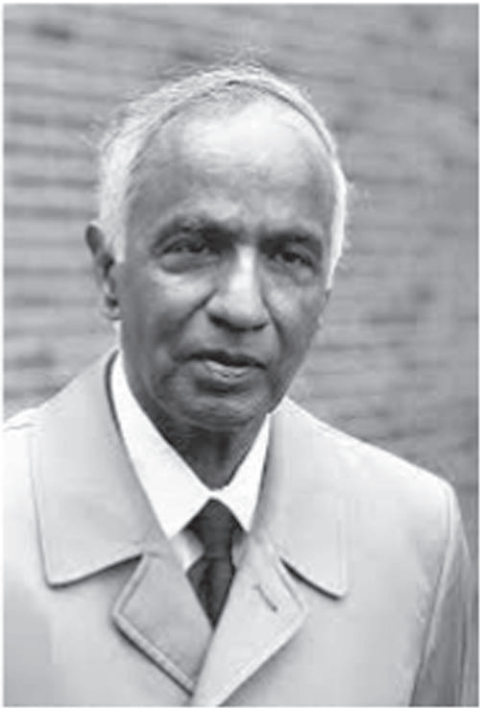

Figure 9. Dr. Subrahmanyan Chandrasekhar, Professor at the University of Chicago, Editor of ApJ during 1952–1970, and recipient of the Nobel Prize for his discovery of the limiting mass of white dwarfs.

problem was how to organize the Journal as it was growing so rapidly. In 1970 the Journal published about 500 papers per year for a shelf space of 0.3 m. He did that with one secretary, one copyeditor, and one production person. By 1999 that grew to about 5000 papers per year in a larger format, a shelf space of 1.8 m and a staff of 20. I could never say "No" to Chandra, so I started as Editor in 1971 and continued to 2000, or 29 yr. Probably one reason why he selected me was the work that I had voluntarily done in producing General Indices.

I decided that I would make no changes to the Journal during my first year as Editor until I understood why things were done the way they were. The exception was to print paper abstracts in full-sized type font because astronomers were no longer reading all the papers, but only the abstracts of many of them. Over the years I made many changes, which were later followed by other journals, namely:

1. I thanked every reviewer for his/her report with a personal letter. I reasoned that if the reviewer spent hours or days in reviewing a paper, I could spend at least 10 minutes writing a letter of thanks.
2. I kept referees informed of all future actions on a paper until acceptance or withdrawal. If the paper needed to go to another referee for arbitration, I kept the original referee informed about the later correspondence.
3. I never asked a referee for more than two reports, reasoning that a referee would get tired of the paper and give in too easily. Instead, I went to another referee for arbitration. In a few cases, I went to a third referee.
4. I did not consult an opponent of the authors for reviews. If I had, the reviewing would never end and the authors would probably go to another journal.
5. I sympathized with any scientist who would see his work being criticized in print without his/her prior knowledge. Therefore, if I saw that a manuscript criticized another author, I sent the manuscript to the criticized author for his/her comments but not to act as a referee. Then those comments and the author's reply were sent to the referee to be considered in writing his/her report. I kept the criticized author informed about all later actions on the paper.

Initially in the 1970s all the correspondence was done with typewriters. I typed the bodies of letters and my secretaries added the beginnings and ends of letters. With the advent of computers, this became easier. Then communication occurred by email, both to the authors and referees. Also, the manuscripts were transmitted by email, which was much faster. That made the consulting of referees abroad much easier. We were already receiving many manuscripts from abroad, so I tended to consult referees abroad roughly as often as we received manuscripts from abroad.

By 1989 it was obvious that I could not oversee the review of all incoming manuscripts myself, so I started to select Scientific Editors who would select referees and oversee the reviewing. The number of those gradually increased to 15, some of whom were abroad. Thus the Journal truly became "An International Review of Spectroscopy and..."

There were technical and financial changes to the Journal, some of which were suggested by the University of Chicago Press staff and the AAS Board. Some of those were:

1. Chandrasekhar wanted to transfer ownership of the Journal to the AAS because he feared that the time might come when the University of Chicago Press might seek to make a profit from its journals, rather than to act as a non-profit organization. (That did happen after the Journal left the Press.) The transfer was arranged by Editor Chandrasekhar and AAS President Martin Schwarzschild. It was agreed that the Journal would not be seen as a source of income for the AAS.
2. In determining the ratio of page charges to subscription rates, we reasoned that the page charges should pay for the first copy printed and that the subscription rates should pay for printing and distributing of additional copies. That meant that if the amount printed or the number of subscriptions changed, the budget of the Journal budget would not become unbalanced.
3. We worried that future events, such as the government suddenly declining to fund page charges, might affect the

budget seriously, so we always kept a reserve fund of half of the annual income of the Journal. The AAS wanted to increase that to two-thirds of the income.

4. The Press found paper stock that would preserve the detail and contrast of halftones. That meant that most photographs could be included within the papers, rather than on glossy stock at the ends of the issues.
5. We decided to add email addresses to papers so that readers could correspond with authors directly. We added subject headings to papers so that the Press could generate Annual and General Indices.
6. With the growth of internationalization in astrophysics, authors frequently published papers in several journals. I noted the arbitrary differences in style in various journals, such as having section headings or tables with Roman numbers or Arabic numbers and numerous differences in reference list formats. It was a nuisance for authors to remember the different styles of different journals. In 1989 I arranged to meet in Paris with the Editors of A&A and MNRAS to standardize styles. We easily agreed in 15 different areas and I published the common style requirements (Abt 1990).
7. Peter B. Boyce, AAS Executive Director, obtained an NSF grant for $500,000 to develop an online edition of the Journal, which started in 1996 as one of the first journals available in that form. By 2015 the printed version of the Journal was terminated, as did those for many other astronomical journals.
8. When I reviewed papers myself, I always identified myself to the authors, but I do not recommend that younger scientists do that. If a referee, who does not have a permanent position or is applying for grants, has recommended that a paper be rejected, a vindictive author might seek revenge against the referee.
9. During most of my tenure, I was helped by Alex Dalgarno as Letters Editor.

13. Blue Stragglers

Blue stragglers are stars on the main sequence in HR diagrams that are above the turn-off points. Why are they still on the main sequence whereas other stars with similar masses have deleted their core hydrogen and became giants? In the 1960s and 1970s the most popular explanation (McCrea 1964) was that they were members of double stars in which the evolved companions were transferring hydrogen-rich material onto the primaries. However, several astronomers studied blue stragglers and found that few of them were double stars. Observations by Pendl & Seggewiss (1975) and Mermilliod (1982) showed that many blue stragglers have abnormal spectra such as Ap, Am, Be, Of, etc. I obtained spectra of 16 blue stragglers (Abt 1985b). For those with ages $10^{8.3}$–10^9 yr, 62% were Ap stars, mostly Ap(SrCr) with low rotational velocities, confirming what Pendl & Seggewiss found. Those are the kinds of stars found by Babcock (1958) to have strong atmospheric magnetic fields ($\sim 10^3$ Gauss). Schüssler & Pähler (1978) and Hubbard & Dearborn (1980) found that strong magnetic fields in B4-A5 stars will cause magnetic mixing in the interiors of stars, and hence bring hydrogen into their cores.

How about the intermediate-aged cluster stars that are not Ap stars? Abt (1979) found that it takes 10^8 yr to produce Ap(Sr, Cr) spectra, so those could be ones that will later become Ap stars, although strong internal magnetic fields will continue to be present, regardless of what happens to the atmospheric compositions.

Mermilliod (1982) found that blue stragglers in younger clusters, namely O6-B2, usually have broad lines. He and I found mean rotational velocities $V \sin i = 220$ km s^{-1}, compared with 150 km s^{-1} for field O6-B2 stars. Also, 15 such stars in young clusters have emission lines, which are an indication of rapid rotation. So does rapid rotation bring hydrogen-rich material into the cores? Tassoul (1978) does not rule out that happening in massive stars, but admits that there are too many unknown parameters to make calculations, such as core rotation relative to envelope rotation. Therefore, we have two mechanisms that can replenish the hydrogen in the cores of blue stragglers and keep them on the main sequence: magnetic mixing and possibly rotational mixing.

14. The Local Interstellar Bubble

The Local Interstellar Bubble, or Cavity, is a region about 400 parsecs in diameter with the Sun at the center. It was first found with radio telescopes (Figure 10). The Sun drifted into the bubble long after it was formed, and will stay within the bubble for thousands of years more. The lobe to the right was produced by a supernova that left the pulsar PSR 1856–3754 with an age of 3.76 Myr. The lobe around the Pleiades occurred about 50 Myr ago. The main part of the bubble was formed about 160 Myr ago. I determined the latter two ages from noting the youngest stars in those regions (Abt 2011). The gas density in the bubble is 0.05 atoms per cubic cm, about 100 times less than outside the bubble. Phillips & Clegg (1992) and Smith et al. (2007) derived a temperature of 1–2 mdeg in the bubble. Welsh & Lallement (2008) found lines of V I 1032 Å and C II 1036 Å in the bubble. Therefore, the Local Interstellar Bubble is an extremely hot volume with an extremely sparse density caused by three separate supernovae.

15. Publication Studies

In 1980 we had an observatory Director who was having difficulty in balancing his budget, so he proposed closing all the small telescopes (<4 m) because he felt that they were mostly used by students and did not produce important results. I questioned that, so I did a study of the 445 papers published in

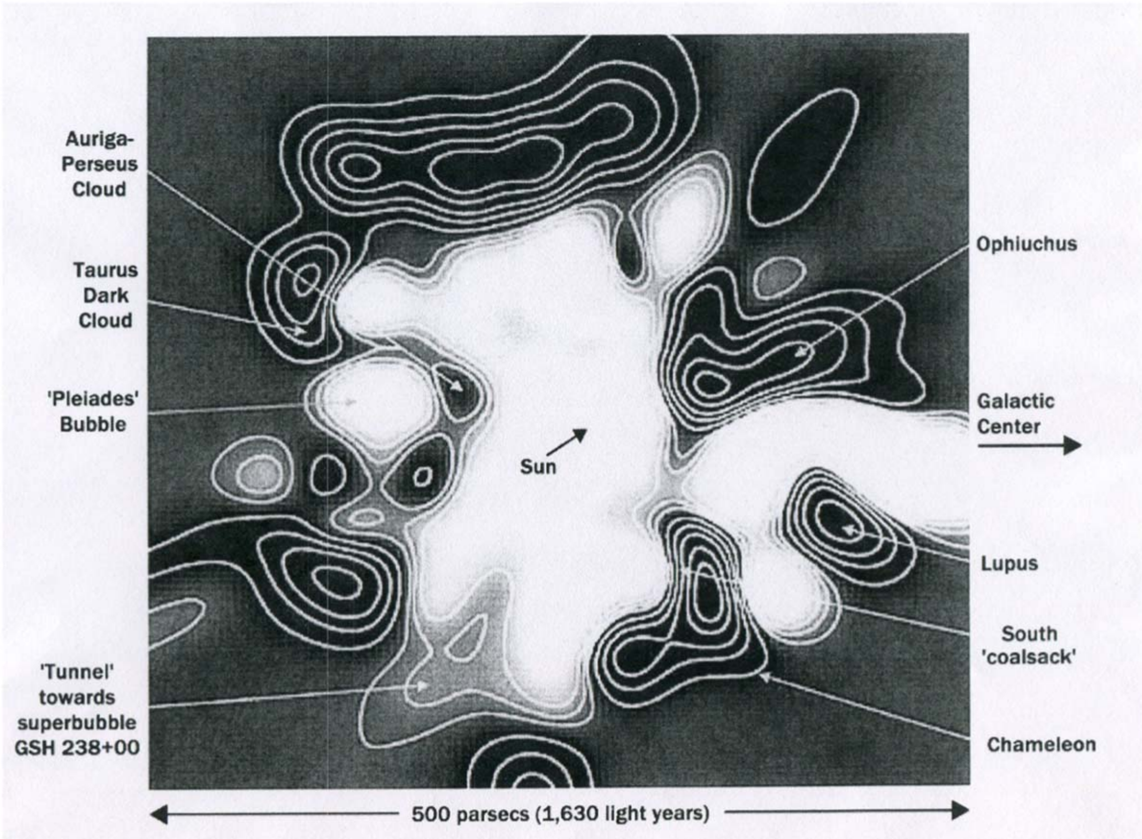

Figure 10. A radio telescope diagram of the Local Interstellar Bubble. Photo by the author.

the previous five years from all of the Kitt Peak telescopes. They yielded 4179 citations. I asked administrators to determine the initial costs (that varied as the 2.4 power of their apertures) and operating expenses of those five telescopes. I found (Abt 1980) that the citations per dollar were several times larger for the smaller telescopes than for the 2.1 m telescope. That stopped the proposal to close the small ones.

That also showed me the usefulness of publication studies, so I published 81 additional studies based on numbers and lengths of papers, citations to them, numbers of authors, countries of the authors, fields of research, etc. Here are a few of those results.

1. The number of citations increased with the number of authors and paper lengths, but not proportionally. Doubling the numbers of authors or the paper lengths increased citation counts by 50% (Abt 1984) on average.
2. *Science* published an article saying that 55% of scientific paper were never cited, but that included abstracts, announcements, book reviews, editorials, errata, and obituaries. The real numbers of uncited research papers are $5.1\% \pm 1.0\%$ for astronomy and $8.1\% \pm 1.2\%$ for physics (Abt 1991).
3. A study (Abt & Garfield 1992) of papers in eight sciences showed that the fraction of multinational papers ranged from 2% in psychiatry to 26% in astronomy and physics. The average paper lengths ranged from 4.6 pages for medical papers to 13 pages in several fields. Revision rates were 8% in physics to 100% in geophysics. The average times for publication ranged from 200 days in physics to 600 days in math.
4. During 1970–2000 the number of American astronomical papers grew linearly with the number of members of the AAS and showed no additional increases upon the completion of new telescopes, the launching of new spacecraft, new technical or scientific capabilities, equipment sensitivities (e.g., the advent of CCDs), or breakthroughs in computational or publishing techniques. When new possibilities occur, astronomers publish better or more important papers, but not more papers. If an organization wishes to publish more papers, they should hire more astronomers, rather than build new equipment.
5. The numbers of single-authored papers in astronomy, biology, chemistry, and physics fit decreasing exponential curves that never reach zero (Abt 2007).

6. For 251 manuscripts submitted to the ApJ in 2006, 6% were rejected, 5% were withdrawn, and 88% were accepted for publication. Of the accepted papers, 30% were reviewed once, 58% were reviewed twice, and 12% were reviewed 3–5 times. The first review averaged 31 days and the second took 44 days. Important papers, i.e., those which received 31–193 citations in two yr, were not reviewed or revised more promptly than less-cited papers. Only for high-energy objects were the papers reviewed marginally more promptly than other papers (Abt 2009).
7. It has often been said that a scientist's best work is done before the age of 35 yr. In 1983 I found that astronomers did their best work between ages 40 and 75 yr., not before age 35. Now that most astronomers work in teams, is that still true? For 14 Russell Lecturers, their peak work was done at 33 yr (Abt 2016). For average astronomers, their publication peak is in their 40s and half of their citations are received for papers written between ages 28 and 67 yr. Thus for outstanding astronomers their best work in done before age 35, but for average astronomers it is later.
8. Do small or large teams produce more citations to their papers? I (Abt 2017) looked at 1343 papers published in A&A, ApJ, and MNRAS early in 2012 and citations in the following 4.5 yr. Large teams produce 2 times more citations than small teams; that was found not to be due to self-citations. However, if we look at normalized citations (citations per astronomer), members of small teams do 6 times better than members of large teams. Large teams tend to produce more data but small teams emphasize physical processes.
9. For the centennial of the IAU, I looked at where astronomical papers were published (Abt 2019). A hundred years ago they were written in Chinese, English, French, German, Italian, Japanese, Russian, and Spanish. Now 99% of the world's 160 astronomical journals are published in English. The number of papers has increased exponentially. Observatory publications, conference proceedings, theses, and private communications have nearly disappeared in research usage in favor of journals.

16. Final Comments

I have always had so many ideas for research projects that when one set of projects is finished, I often shifted to something entirely different. That means that I did not spend most of my career in one field and therefore never qualified for a major award. The above summarizes ~50 papers out of a total of 330 papers I published. The others were studies of individual stars or clusters of interest.

In 2017, I was named in the Who's Who Lifetime Achievement. Marquis Who's Who in America is the world's premier publisher of biographical profiles. By now it has contained the biographies of 5900 of the most famous Americans in politics, science, literature, the arts, dance, sports, acting, and 11 astronomers. The Lifetime Achievement recognizes individuals that have achieved greatness in their field.

I have enjoyed working with many other astronomers, helping them use equipment in the US and Chile, and attending ~30 conferences in 27 different countries. In particular, in 13 trips, I helped Chinese astronomers, but they introduced me to their rich culture.

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