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HORACE WELCOME BABCOCK
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A Biographical Memoir by

GEORGE W. PRESTON

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Photograph by Mount Wilson and Los Campanas Observatories

Horace W. Babcock.

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BY GEORGE W. PRESTON

HORACE BABCOCK'S CAREER at the Mount Wilson and Palomar (later, Hale) Observatories spanned more than three decades. During the first 18 years, from 1946 to 1964, he pioneered the measurement of magnetic fields in stars more massive than the sun, produced a famously successful model of the 22-year cycle of solar activity, and invented important instruments and techniques that are employed throughout the world to this day. Upon assuming the directorship of the observatories, he devoted his last 14 years to creating one of the world's premier astronomical observatories at Las Campanas in the foothills of the Chilean Andes.

CHILDHOOD AND EDUCATION

Horace Babcock was born in Pasadena, California, the only child of Harold and Mary Babcock. Harold met Horace's mother, Mary Henderson, in Berkeley during his student days at the College of Electrical Engineering, University of California. After brief appointments as a laboratory assistant at the National Bureau of Standards in 1906 and as a physics teacher at the University of California, Berkeley, in 1907, Horace's father was invited by George Ellery Hale in 1908 to join the staff of the Mount Wilson Observatory (MWO), where he remained for the rest of his career. (Harold

Babcock was elected to the National Academy of Sciences in 1933.)

In 1912, when Horace was born, the Mount Wilson Observatory was in its heyday of expansion. The newly completed 60-inch telescope, then the largest in the world, was to be eclipsed within the decade by the 100-inch Hooker telescope under construction nearby.

Thus, Horace Babcock, son of a Mount Wilson astronomer, grew up in the environment of a great observatory in the making. In his oral interview for the American Institute of Physics (AIP) Horace recalls that many of his childhood recollections relate to Mount Wilson, seeing the astronomers, being aware of construction on the mountain, in particular "the noisy riveting of the 100-inch dome. . . So it was only natural that I would have an early strong interest in astronomy." Horace, attracted to science, went to the Pasadena public grade and high schools. For understandable reasons he was also interested in engineering, so much so that he majored in structural engineering at Caltech, and it was only after he graduated in 1934 that he decided to go into astronomy.

Throughout his life Horace was fascinated by fine mechanisms and by electrical and optical instruments. His father cultivated these interests by involving Horace in his own work from childhood. But, Horace remarks in his AIP oral interview, his father was careful never to try to make major decisions for him. Rather he tried to show Horace where opportunities and interests might lie. For example, he introduced Horace to photography and helped Horace build a 6-inch telescope. In 1928 Horace, then 16 years old, spent six weeks as a volunteer in the MWO optical shop, where he learned how to make lenses, mirrors, and prisms. During the summers of 1930, 1932, and 1935 he worked as a volunteer observer with the Snow solar telescope and

150-foot solar tower on Mount Wilson, where he produced spectrograms of the solar chromosphere, especially in the infrared. He published five short papers about these activities in the *Publications of the Astronomical Society of the Pacific* (one with his father). This was a period of learning outside the conventional paths of public education. He was learning practical spectroscopy, measuring wavelengths, and acquiring familiarity with the reference materials of observational astrophysics. In the course of these adventures he inevitably became acquainted with many astronomers at Monastery mealtimes. "The Monastery" was the official name of the (at that time all-male) sleeping and eating facility for observers on the observatory grounds. In the spring of 1930 Horace accompanied an MWO party that included his father, Seth Nicholson, and Ted Dunham to observe a total solar eclipse in Nevada.

In 1930 Horace also began his undergraduate studies at Caltech, a personal goal since childhood. He was well aware that the design and assembly of a 200-inch telescope were under way there. He majored in engineering (as his father did in Berkeley), but also studied physics (electricity and light, which he liked best). There was no undergraduate astronomy course at Caltech at that time. Horace wanted to study astronomy, so he wrote a petition asking that such a course be taught and posted it on a campus bulletin board. Many students signed it, and the next year such a course was offered by physicist John Anderson, head of the 200-inch telescope project under Hale. Horace was pleased to think that his petition had played a role in this development.

By 1934, when he graduated from Caltech, Horace knew that he wanted to be an astronomer. He realized that he would need a Ph.D., unlike his father who had gone to work at MWO with only a B.S., and Walter Adams, the director, who had only an M.S. Horace hoped that when the 200-inch telescope went into operation (then expected to happen around 1938) he might have a chance to participate in its use. Horace had visited Palomar Mountain before anything had been built there, and he was taken by the challenge of locating the 200-inch in that primitive environment.

The graduate school that most closely aligned with Horace's interests was the University of California, meaning course work in Berkeley and thesis work at the Lick Observatory on Mount Hamilton in California. "I didn't have much inclination to think of going to an Eastern university, which would not be strong on observing anyway. The University of California had the Lick Observatory and it was the place to go." Horace did not have a scholarship or assistantship during his three years on the Berkeley campus; his father paid his expenses. Horace's uncle, Ernest B. Babcock was a biology professor at Berkeley (also elected to the National Academy of Sciences, in 1946). It is possible that Horace lived with his family there.

Horace found the Berkeley Astronomy Department to be quite old-fashioned ("post-mature" to use the euphemism in his oral interview). It was dominated by several big names in "theoretical astronomy," a term which at that time in Berkeley meant "orbit theory." Horace had already been exposed to the new astrophysics that Hale had made the centerpiece of research at the Mount Wilson Observatory, but only Donald Shane, subsequently director of Lick Observatory, taught astrophysics at Berkeley in 1935. However, there were good physics courses. Horace enjoyed those offered by Robert Birge, Francis Jenkins, Harvey White, and particularly by J. R. Oppenheimer, whom Babcock regarded as remarkably articulate. Of course, there was the attraction of the Lick Observatory. While in Berkeley, Horace became acquainted with Nicholas Mayall of Lick Observatory, under whom he would later pursue his thesis observational work. Babcock regarded Mayall's extragalactic research with his nebular spectrograph at Lick's Crossley telescope as a "shining example of achievement."

Horace credits Mayall for proposing measurement of the rotation of the galaxy M31 (Andromeda Nebula) as a Ph.D. thesis topic. Mayall also provided a spectrograph at the 36-inch Crossley reflector capable of making the measurements, and he offered suggestions about places to make observations in the outskirts of M31, faint emission wisps. Horace took up these suggestions in his fourth year of graduate work, now supported by a fellowship, on Mount Hamilton. Most of his spectra were obtained with a long slit placed along the major axis of the galaxy. Velocities in the inner regions with sufficient surface brightness were derived from wavelength displacements of absorption lines produced by myriads of unresolved stars. Additionally, he observed five faint nebulosities identified by Mayall in the outer reaches of M31, where starlight is too weak to measure. We now recognize these wisps as H II regions similar to the Orion Nebula located nearby in our Milky Way Galaxy. They could provide velocities because they shine brightly at a relatively few discrete wavelengths due to the fluorescence of gas clouds illuminated by hot stars. The work was arduous. Exposure times were long, 10 to 20 hours (several nights spent obtaining each spectral photograph), but the results were spectacular. They are displayed in his thesis, published as Lick Observatory Bulletin, No. 498 in October 1939 and now reproduced in a more readily available journal *Publications of the Astronomical Society of the Pacific,* volume 116.

The rotation curve produced by this work (a plot of line-of-sight velocity derived from the optical Doppler effect versus angular position along the major axis of the galaxy) did not decline outside the galaxy's luminous bulk. Rather, it continued to rise to the outer angular limits of Horace's observations. This behavior was contrary to the expectations for Keplerian motion about a central gravitating body (in which velocity decreases inversely as the square root of distance from the center of the system). He analyzed the velocities, advised by Lick astronomer R. J. Trumpler, and found that they did not match the rotation curve calculated for the constant mass-to-light ratio, then the usual assumption made for starlight. Upon converting his radial velocities to angular velocities about the center of M31, Horace noted in his thesis that "the obvious interpretation of the nearly constant angular velocity from a radius of 20 minutes of arc outward is that a very great proportion of the mass of the nebula must lie in the outer (dim) regions." In retrospect we now know that Horace had come upon the crucial evidence for the existence of dark matter, but like Wegener's continental drift, it was a discovery before its time. No one could make any sense of it. He completed writing his thesis by June 1938 and got his Ph.D.

W. H. Wright, the Lick director, arranged for Horace to make oral presentations about his M31 rotation curve at the 1939 annual meeting of the American Philosophical Society (APS) in Philadelphia and at the dedication of the brand-new McDonald Observatory in Texas immediately afterwards. His paper fit right into the subject of the APS symposium, "Structure and Dynamics of Galaxies," and he discussed it afterward with Bertil Lindblad and Jan Oort, two of the world experts who gave review papers there. Babcock's was the first published rotation curve that extended significantly beyond the bright nuclear bulge of M31 into the spiral arm regions of the galaxy. Everyone agreed that his results were important, but no one had a good explanation for them. Thus, Horace's graduate education concluded on a satisfactory though puzzling note; at the least he had attracted some attention. Shortly thereafter Otto Struve offered him a position at Yerkes and McDonald Observatories. Horace believed that his presentation at McDonald got him the job.

GETTING STARTED

Before going to Yerkes, Horace enjoyed the summer of 1939 as a postdoc at Palomar working on a project partly financed by 200-inch funds. He used a small spectrograph put together around a fast Schmidt camera and a grating provided by his father, who was in charge of the MWO grating laboratory at that time. He and Josef Johnson, a graduate student working with Caltech astrophysicist Fritz Zwicky, took spectra of the night sky, which they continued through the year. Their system was responsive well into the UV, and it showed many night-sky bands in that region, which we now know are mostly emitted by various excited levels of terrestrial, atmospheric molecular oxygen (O_2). They also tried to trace the night-sky brightness variations through the night and through the year, but it was too complicated to unravel. One of their conclusions: "For the photography of faint nebulae it would seem advantageous to filter out the ultraviolet light." Perhaps because of their UV observations, the Palomar high command decided not to try to include that spectral region in the Palomar Sky Survey to be conducted by the 48-inch Schmidt telescope. Consequently, the Schmidt corrector plate was made of plate glass (to block the UV) rather than from UV transmitting glass. This design feature would increase the limiting magnitude of the blue exposures, an important improvement. Babcock, living at Palomar that summer of 1939, was one of the first astronomers to make an extended stay in the Lodge, as it was then called. He liked it and hoped to get a staff job there, but the 200-inch was being put on hold because of World War II, and was far from complete.

MCDONALD AND YERKES OBSERVATORIES

Otto Struve, director of Yerkes and McDonald Observatories by agreement between the University of Chicago and the University of Texas, was eager to hire young astronomers trained at other top observatories to work at McDonald. Wright's recommendations played a significant role in Struve's choices of Horace and his fellow Berkeley graduate student Daniel Popper, according to Osterbrock (at the 2004 Babcock Memorial Symposium). The positions were attractive, because the new 82-inch reflector was then the second largest telescope in the world. Horace would have preferred a job at Mount Wilson Observatory, but his father and Director Walter S. Adams, a close friend of the family, told him the experience would be useful to him in the long run.

Horace, by virtue of his thesis experience, was very interested in nebular spectroscopy, but even the fastest spectrograph of the 82-inch, used at the Cassegrain, was far too slow. Instead he had to work on low-resolution spectroscopy of relatively nearby bright stars, collaborating with other astronomers on their programs. One was with Popper on nova-like variables; another, with Philip Keenan, was devoted to spectra of stars near the north galactic pole.

Struve asked Horace to design a fast nebular spectrograph to be used at the prime focus, a concept Frank Ross, then a senior Yerkes staff member, had suggested to him. Horace had little experience in designing instruments, but his engineering training at Caltech and his discussions with his father had prepared him admirably for the task. He designed a grating spectrograph (unusual because good gratings were rare); his father, now supervisor of the Mount Wilson grating laboratory, was able to provide one for him.

It was pierced, so it could be used with a parabolic mirror collimator on axis, the favored MWO design at the time.

There was no instrument maker at McDonald, so Horace had to make the drawings and send them back to Williams Bay, where Yerkes machinist Charles Ridell constructed the mechanical parts. George Van Biesbroeck, the astronomer in charge of the shop, modified the plans, probably to simplify the work, before handing them over to Ridell, and neither Van Biesbroeck nor Struve felt called upon to notify Horace of the changes. He learned of them only when the parts arrived at the remote McDonald observing site, where the instrument could not be assembled and used effectively. Horace, who had been counting on using the spectrograph, wrote a hot letter to Struve asking why he had not been consulted, and Struve replied at once, chastising him severely for daring to question the judgment of his elders. In fact both of his elders were quite out of date about spectrographs, as demonstrated by the other instruments at McDonald, but as a result Horace did not manage to do nebular spectroscopy there. In spite of this early confrontation Horace expressed admiration for Struve's research and management style at the Yerkes-McDonald enterprise.

After World War II, Horace's fast B spectrograph was slightly modified by Thornton Page, who used it to measure the velocity differences in pairs of galaxies. The result Page found, that the indicated masses of the individual galaxies were larger than expected, was another manifestation of dark matter, not understood by Page or anyone else at that time. After Page left Chicago, the B spectrograph was used by Margaret and Geoffrey Burbidge to measure rotation curves of numerous other nearly edge-on galaxies. Thus, Horace's instrumental efforts at McDonald enabled important later extensions of his thesis work at Lick.

Soon after completion of the spectrograph in 1941 Struve asked him to take on the coronaviser, a device on loan from Bell Telephone Laboratories that had been invented by A. M. Skellet for observation of the solar corona outside of eclipse. Among improvements made by Babcock was use of an RCA 931, the first astronomical application of this precursor of the famed 1P21 photomultiplier.

Within the year, Horace was rotated from McDonald back to Yerkes for a long stay and a chance to write up his results. There he had many discussions with S. Chandrasekhar, then working in stellar dynamics, about the M31 rotation curve. Horace liked Chandra and enjoyed hearing his talks, but he wrote that the acclaimed theorist didn't understand much about observational astronomy.

While at Yerkes, Horace met, wooed, and married Margaret Anderson, an eighth-grade school teacher at Williams Bay High School. Later that year the two went back to McDonald, but the year was 1941 and America was close to entering World War II. Scientists were in demand for weapons projects, especially experimental physicists with skills in electronics. Albert Whitford had been recruited to the MIT Radiation Lab to work on radar in 1940; he had recruited Gerald Kron to come there, too, and now Kron recruited Horace, who arranged with Struve to take an indefinite leave of absence. He and his wife drove across the country (after a visit to his parents' home in Altadena), with perhaps a stop at the last big prewar American Astronomical Society meeting at Yerkes (in September 1941), and then on to Cambridge.

WORLD WAR II

Horace arrived in Cambridge knowing little more than that the Radiation Laboratory was engaged in electronics. Security was surprisingly tight and he was given to feel that he shouldn't be asking questions. He was attached to a group concerned largely with cathode-ray circuitry to present airborne radar information, all of it mostly new to Horace. He picked up most of his electronics there by osmosis. Horace did not begrudge the time, as most of the astronomers he knew were also engaged in military research. However, he yearned to return to California, and he seized an opportunity to join a new war laboratory at Caltech, where he worked at first on aircraft rocket launchers, on the development and subsequent testing of new types of rockets at Goldstone and China Lake, and on development of automatic sights for firing at surface targets.

Subsequently, in 1945, he and Carl Anderson were dispatched to Los Alamos to discuss development of a delivery system for the atomic bomb and radiotelemetry for testing bomb drops from B-29 airplanes, but it seems that Horace did not actually participate. He comments in his oral interview that he felt the United States should have made a demonstration of the bomb without using it on civilian targets. His thought at the time about drops in Japan: "Why should I get involved? I don't particularly like it if they are going to drop this thing on a city."

SCIENCE YEARS

"After the war was over, the big question was how do we get back into astronomy?" Horace, luckily, was well-positioned. In the Caltech Rocket Project he became reacquainted with Ira S. Bowen, the Caltech physics professor about to assume the directorship of the newly formed Mount Wilson and Palomar Observatories, whom he had met earlier at Lick. They had worked together organizing rocket tests and analyzing results. Bowen, recognizing Babcock's rare combination of astronomical knowledge and optical and electronic skills offered Horace a position at the observatories to become effective January 1, 1946, the first day of Bowen's directorship. Horace accepted and remained at the observatories for the rest of his professional career.

Bowen hired Horace with the understanding that Horace would divide his time equally between instrument development and personal research. Shortly before the outbreak of World War II, Hans Bethe discovered the sequence of nuclear reactions that powers the sun and stars. Mindful of Bethe's discovery Bowen gave high priority to observatories involvement in the derivation of atomic abundances in stars and galaxies as part of a broader inquiry into nuclear reactions and energy generation in stars. Accordingly, he wanted a new microphotometer that could extract abundance information from stellar spectrograms to be produced by the large coudé spectrograph of the 200-inch telescope. As a first assignment Bowen asked Horace to design and build such a microphotometer. His reaction: "OK, this was an assignment and I had to do it." He had no assistant. He did all the electronics himself: "design, purchase of every transformer, every vacuum tube socket." The mechanical parts of the machine were built in the observatory shops. He got it to work in 1948, but Horace regarded it as a failure because it was never used in a systematic way by his colleagues. He admitted that the machine was perhaps too elaborate and thus turned people off. He regarded the effort as educational, but "I have to remark that the time was wasted." Two admirable characteristics of Horace Babcock's professional style emerge from this episode: the avant-garde nature of his designs and his frank assessment of outcomes.

STELLAR MAGNETISM

While completing his microphotometer assignment, Horace also chose his first venture into scientific research at the Mount Wilson and Palomar Observatories. He comments in his oral interview that he sat down on his front porch one evening and said to himself, "I'd better come up with something here. What am I going to do in research?" He mused about what could be learned from the radiation that arrived from celestial sources. In 1946 astronomers were measuring frequency (or wavelength), intensity, and position of radiation from celestial sources, but no one was doing much with polarization. From this reflection his thoughts turned to Hale's discovery of magnetic fields in sunspots (atoms in magnetic fields produce polarized light) and he asked himself under what circumstances might one detect a magnetic field in a distant star. Reasoning by analogy to the sun's general magnetic field, "I got to thinking, suppose you had a star with a far stronger field than the sun . . . thousands of gauss, would there be any chance of detecting it?" By way of justification for such a notion he imagined that strong fields might be generated by some dynamo process in rapidly rotating stars: "I really did have the notion that rapid rotation would somehow result in strong magnetic fields." Accordingly, he estimated the stellar field strengths that might exist if magnetic field strength scaled with rotation. The sun with a general field of 50 gauss (the erroneously high but accepted value at that time) rotates at the speed of about 2 km/s at its equator. Most A-type stars (stars hotter and more luminous than the sun) rotate with speeds of 100 km/s or more at their equators, so fields ~1000 gauss might occur. Horace may or may not have been aware that this same speculation had been published 10 years earlier by the Dutch astronomer M. Minnaert in volume 60 of the British journal *Observatory*.

Could such fields be detected in the integrated light of the star? Horace (1947) made elaborate calculations of the Zeeman effect (the wavelength shift between polarized atomic line components) that would be produced in the integrated light from a star that possessed an embedded dipole field. Under the most favorable circumstances—when the dipole axis is parallel to the line of sight to the observer—a dipole field star with polar field strength of a few kilogauss would produce displacements of a few microns between the oppositely circularly polarized Zeeman components in the focal plane of the most powerful spectrographs available at the Mount Wilson 100-inch reflector. Detection of this miniscule effect was a long shot and Babcock knew it, but he was intrigued. He took the idea to Bowen, who said, “Why don’t you give it a try?”

How would he make such measurements? In short order he assembled an analyzer of the type used by Pieter Zeeman himself, suitably modified for use at the large coudé spectrograph of the 100-inch reflector. It consisted of a quarter-wave plate cemented to the front face of a Nicol prism. The quarter-wave plate was oriented so as to direct incoming left and right circularly polarized light into the O (ordinary) and E (extraordinary) beams of the Nicol prism to which it was cemented. Thus, this analyzer separated oppositely circularly polarized components of starlight at the entrance aperture of the spectrograph, producing dual spectra of the star with opposite circular polarizations side by side on a photographic plate in the focal plane of the spectrograph camera. The two stellar spectra were flanked by reference spectra produced by an iron arc located near the spectrograph entrance slit. The iron arc spectra (containing myriads of Fe I emission lines of known wavelengths) established a coordinate system on the photographic plate within which it was possible to measure the small wavelength shifts between the two polarized spectra that signaled the presence of a magnetic field. To complete his analyzer Horace needed a quarter-wave plate, so he turned to his father for help. Harold had learned how to select, split, and test mica plates for similar analyzers used to measure the magnetic fields in sunspots at the Mount Wilson solar towers.

Next, which stars to observe? The spectral lines produced by stars rotating at speeds of 100 to 200 km/s are shallow and hundreds of times wider than the Zeeman shifts Horace expected from his scaling argument. However, Horace was aware that a small fraction (~10 percent) of the A-type stars have sharp lines and, as well, abnormally strong lines of certain chemical elements. He assumed that these were actually rapidly rotating stars with rotation axes pointed toward the earth. He supposed that the special aspect of this group was responsible for their sharp lines and spectral peculiarities. Alignment of the magnetic and momentum axes of such stars would make them naturals for his first observational experiments.

Horace took his analyzer to the Mount Wilson 100-inch telescope and during his first experimental run discovered a believable magnetic field of ~1 kilogauss in the sharp-lined peculiar A-type star 78 Virginis. All of his expectations were fulfilled with unanticipated speed. To recapitulate: Horace was hired in January 1946, ruminated on his front porch in February, made his analyzer in March, observed 78 Virginis at Mount Wilson in April, May, and June (see Babcock, 1947, Table 1), measured his spectra in July and August, and submitted his seminal paper to the *Astrophysical Journal* in September 1946. Thus, in the first nine months of his appointment to the staff of the observatory he had discovered a new astrophysical phenomenon. In doing so he created a new astrophysical discipline, one that took on unanticipated dimensions with the passage of time, as we shall see below.

Following this discovery Horace could get as much telescope time as he wished. He initiated a major search for stellar magnetic fields, principally among ~100 sharp-lined A-stars, by making a series of Zeeman observations for each.

The search was conducted primarily with the coudé spectrographs of the Mount Wilson 100-inch and Palomar 200-inch telescopes over the course of a decade. The characteristic duration of an observation was one hour. His research assistant, Sylvia Burd, measured his spectrograms and calculated magnetic fields from them by use of his prescriptions. Accordingly, she deserves some of the credit for the steady stream of discoveries that followed from their work. Although the field polarity 78 Vir remained positive with the passage of time and didn't change much, Babcock began to find many stars with variable magnetic fields that reversed polarity, HD 125248 being the first (1951). He concluded his survey with publication of a monumental *Catalogue of Magnetic Stars* (1958), which contains more than 1200 measurements of magnetic fields collected for more than a decade, together with radial velocities, notes, and star-by-star commentaries, all of which have proven invaluable to subsequent investigators. His stellar work after 1958 was concentrated on a few stars of particular interest. Periodic magnetic variability has proven to be invariably the rule among the A-type stars, whenever field strengths significantly exceed the errors of measurement, and the periods are invariably the periods of spectrum variation, a phenomenon known since the beginning of the 20th century. In the course of his investigations Horace also discovered the crossover effect, the appearance of peculiar line profiles that occurs in some stars at phases when the magnetic field reverses polarity.

Horace (1949) was well aware that the Oblique Rotator (a model in which magnetic variation is an aspect effect produced by a static magnetic field inclined to the rotation axis of a star) under plausible circumstances could produce the crossover effect, the field variations, and the changes in spectral line strengths. In fact, he may have invented the model, though history is a bit obscure on this point.

It is certainly the model of choice among today's experts, who have created an impressive array of experimental and computational techniques to study stellar magnetic variability. Furthermore, the now greatly augmented statistics of rotation for stars more massive than the sun demonstrate beyond reasonable doubt that the slowly rotating peculiar A-type stars are a species *sui generis*, rather than the "pole on" fraction of a rapidly rotating population. However, so far as I can ascertain Horace never accepted the Oblique Rotator interpretation of his data, arguing as late as 1958 that strong, coherent magnetic fields are a property of rapidly rotating stars, detectable only in that small proportion of such stars that happen to be observed pole-on. I attribute his preference for an explanation couched in hydromagnetic oscillations to his intimate familiarity with the complex details of solar magnetism (more of this below) and to the line of thought that led to his first successful detection in 1946.

History will record that Horace's discovery and empirical exploration of magnetic phenomena in hot main-sequence stars was his first great contribution to astrophysics. His pioneering efforts have inspired a host of subsequent searches for magnetic fields elsewhere in the Hertzsprung-Russell diagram: in cool solar-type stars, degenerate stars, interacting binaries, and pre-main sequence stars. And the oblique rotator, which explained his stellar observations, has become the paradigm for modeling of pulsars and magnetars.

SOLAR PHYSICS

Three scientists working independently at the Mount Wilson Observatory in the 1950s and 1960s created the underpinnings of what has become known as the solar-stellar connection, namely, the application of what has been learned from detailed investigation of activity on the solar disk to phenomena seen in the integrated light of remote, unresolved stars. In 1961 Horace incorporated the rich lore of solar activity, much of it accumulated at the Mount Wilson solar towers, into an extraordinary phenomenological model of the 22-year solar cycle. A year later, in 1962, Caltech physicist Robert Leighton and his colleagues, Robert Noyes and George Simon, working at the 60-foot Mount Wilson solar telescope reported discovery of the five-minute solar oscillations that have led to modern-day solar and stellar seismology. In a subsequent analytic treatment of Babcock's model in 1969 Leighton quantified Babcock's results, producing what is now known as the Babcock-Leighton dynamo that powers the solar cycle; nowadays, models based on this dynamo are called Babcock-Leighton models. Approaching the solar cycle independently on the basis of his own pioneering work on stellar chromospheres, Olin Wilson undertook a successful decade-long search at the Mount Wilson 100-inch telescope in the 1970s for stellar analogs of the solar cycle. Such cycles abound among solar-type stars. Thus, Horace's efforts were part of a major thrust in solar physics at Mount Wilson that began with George Ellery Hale's discovery of magnetic fields in sunspots at the 60-foot solar tower a half century earlier.

Horace's contributions to these seminal developments were several-fold: (1) working with his father, then retired, he developed a magnetograph at Hale's Solar Laboratory in Pasadena in 1952. This was a marvelous device that could scan the solar disk on a timescale of ~1 hour to produce a map of the surface magnetic field of the sun; (2) with this device he and his father detected the weak (~1 gauss) general high-latitude poloidal field of the sun in 1955; and (3) Harold Babcock used Horace's magnetograph to discover a reversal of this poloidal field during 1957-1958, which Horace incorporated into his model of the 22-year solar cycle.

Perhaps the most important aspect of Babcock's modeling was the ingenious way he used the complex of prior observational data to guide construction of his model, so that it would be at once reasonably compatible with the physics of magnetized plasma and, as well, with what was known about the solar surface at that time: the behavior of the high-latitude poloidal field (his discovery) including its polarity reversal (his father's discovery); the generation of sunspots, particularly bipolar magnetic regions; the polarities; polarity reversals every 11 years; and orientations of these regions, their numbers, integrated magnetic flux, and latitude drift during the cycle, inter alia. Horace's model was a semi-empirical tour de force.

In 1957 Robert Howard, using an improved version of the magnetograph at the 150-foot solar tower on Mount Wilson, began a series of daily observations of the sun, which continues to this day, now under the direction of Roger Ulrich at the University of California, Los Angeles. Because of their value for predicting flares and magnetic storms, these observations are reported in *Solar Geophysical Data* published by the National Oceanic and Atmospheric Administration. Today advanced technologies for the measurement of solar magnetic fields have proliferated at Big Bear Observatory in California; at the National Solar Observatory; at a complex of European facilities at Observatorio del Teide in the Canary Islands; and at solar observatories in Crimea, Japan, Russia, Ukraine, and elsewhere. Horace Babcock really started something.

INVENTION AND INSTRUMENTS

In the midst of his scientific research Horace found time to design, build, improve, and propose a remarkable array of scientific instruments for diverse purposes. Earliest examples, his spectrographs at Palomar and McDonald and the coronaviser, were undertaken as assignments. However, the stellar Zeeman analyzer and the solar magnetograph were initiatives undertaken to further his own research interests. He evidently regarded the magnetograph as a work in progress, for he continued to improve the version he installed at the 150-foot solar tower off and on until 1961, nine years after his first effort in Pasadena.

Inspection of his bibliography reveals a total of 20 papers devoted to various electro-optical mechanical devices. The timing of some of these papers relative to other papers on totally unrelated topics is remarkable. Thus, his seminal 1947 paper about the detection of a stellar magnetic field was followed within a year by a paper on the design and construction of an autoguider to increase the efficiency of observing at the coudé focus of a telescope, and shortly after that a theoretical inquiry into magnetic intensification of spectral lines. His very important 1951 paper on the periodic reversing magnetic field and associated crossover effect of HD 125248 is accompanied by a report in the same year on the performance of the Mount Wilson ruling engine, which Horace supervised, and the quality of diffraction gratings produced by it.

In 1953, while preparing a paper about the magnetograph and its use, he also published a seminal paper entitled *The Possibility of Compensating Astronomical Seeing*, a description of procedures by which it might be possible to produce diffraction-limited images of celestial sources at ground-based telescopes. By publication of this one paper Horace Babcock created adaptive optics, a new discipline that enables high-resolution imaging science at several major observatories and, more importantly, is playing a central role in the design of all very large optical telescopes of the future. It is likely that this contribution will prove as important for astronomy as any other of his works. In 1963 papers on a periodic magnetic variable star (53 Camelopardalis) and a theoretical inquiry into the possibility of element segregation in a magnetized stellar atmosphere accompanied the description of his astronomical seeing monitors (ASMs) to be used for astronomical site testing. These coeval forays into diverse topics testify to the breadth of Horace's intellectual curiosity and inventive skills.

Horace's supervision of the grating laboratory deserves a paragraph of its own. The impetus for the grating laboratory, like many other things at the Carnegie Observatories, came from George Ellery Hale, whose goal was to get the best possible high-resolution spectra of the stars and sun. Typically, Hale imported physicist John Anderson from Johns Hopkins University in 1912 to make very large gratings for the Mount Wilson telescopes. In 1929 after Anderson had taken charge of the 200-inch project, Harold Babcock succeeded him in the MWO grating laboratory, replacing Anderson's original ruling engine with a more compact machine. Over the years the ruling engine was torn down, modified, and improved continuously, and after about 1935 or 1940 most of the new Mount Wilson spectrographs used gratings ruled with it. The 200-inch coudé spectrograph needed a mosaic of four essentially identical gratings to fill its 12-inch beam, a demanding requirement, and Horace took on the task of making them when his father retired. Horace designed and installed the first interferometric control for the ruling process. By the 1960s the demand for gratings was so large that companies, especially Bausch and Lomb, got into the act seriously, and the grating lab was closed, but in its day it produced perhaps 100 gratings for the Mount Wilson and Palomar Observatories and other observatories around the world. After he retired, Babcock published an engaging account of the history, practices, and accomplishments of the grating laboratory (1986).

THE BIRTH OF LAS CAMPANAS OBSERVATORY

The creation of Las Campanas Observatory was the culmination of Horace Babcock's career. The sequence of events that led to completion of the observatory is complex, now blurred by lack of documentation in some instances and by conflicting memories in others. However, many relevant facts are beyond dispute. First, after 1950 Horace Babcock's role in the affairs of the observatories was on the rise. Director Ira Bowen drew him into observatory administration for reasons about which I can only speculate: his scientific reputation, his skill in instrumentation, and his interest in improvement of Carnegie astronomy. Horace became a member of the Observatory Committee in 1953, was appointed assistant director in 1956, and associate director in 1963, the last of these appointments occurring just one year before Bowen's mandatory retirement at age 65. Horace Babcock became director of the Mount Wilson and Palomar Observatories on July 1, 1964. This path from science into administration strongly parallels that of a predecessor, Walter Adams.

In his oral interview Horace cites the opportunity to develop an important Southern Hemisphere observatory as a major inducement to accept the appointment. On reading his first annual report it is evident that he embraced the opportunity: Horace devotes the entire "Introduction" (*Carnegie Year Book*, 1963) to an outline, published in *Carnegie Year Book* 1 in 1902, of requirements prepared by a committee of astronomers for choosing the site of a Carnegie southern observatory and he goes on to summarize a 165-page proposal for this observatory set forth in *Carnegie Year Book* 2 in 1903. Additionally, a major section of his report was devoted to a discussion of ASMs and the initiation of site testing in New Zealand, Australia, and Chile. In these writings Horace announced that he had a historical institutional mandate to pursue a southern observatory.

The salient events that led to the establishment of this observatory at Cerro Las Campanas are set forth below in the (edited) words of Arthur Vaughan, former observatory staff member who played several essential roles in the story. Arthur assisted Ira Bowen in optical designs for the special wide-field characteristics of the telescopes. He served as astronomer in charge of testing and acceptance of the du Pont telescope mirrors and for two years beginning in 1976 as assistant director for Las Campanas. Vaughan delivered his remarks at the Babcock Memorial Symposium held on the Caltech campus on May 21, 2004.

Vaughan recalls the first meeting of Horace's directorship, held in the reading room of the library at Santa Barbara Street. Horace, standing in the middle of the room, spoke with surprising restraint, outlining his vision for the future under his directorship: the construction of a big new observatory in the Southern Hemisphere, with possibly a Southern Hemisphere 200-inch telescope as well as a new 60-inch telescope that would be located at Palomar. He couched his arguments in terms of institutional goals built upon the opportunities afforded by the southern sky, in particular, the center of the Milky Way Galaxy and the Magellanic Clouds, our nearest extragalactic neighbors. Asked by Spencer Weart how he felt about the prospect of such undertakings, Horace replied,

> Well, it made me apprehensive, of course. I was torn between two points of view. In some respects, I looked with great disinterest at the idea of being director. I knew that it would mean giving up all my own science, and getting into this kind of activity that Bowen had been doing, which really in itself didn't have any appeal. . . Let's just say that by 1963, when I was offered the directorship here, it was clear that at the very least, we were going in for an

important site survey in the Southern Hemisphere, with the idea that we might be building a major telescope. This presented me with a tremendously attractive opportunity . . . the prospect of building a new observatory, with a major new telescope, was such an attractive and challenging idea that I couldn't turn it down . . . And, wisely or not, that's what I got into.

So where did this idea of a southern observatory come from? As noted above, Horace attributed the origins of the project to a 1903 proposal of George Ellery Hale. Then, 58 years later, in 1961, the Carnegie trustees initiated a review of the institution's activities and programs, inviting suggestions from directors and staff members as to possible new directions. Olin Wilson wrote a letter in March 1963 to Carnegie physicist Merle A. Tuve, later communicated to President Haskins and the trustees, arguing that the institution should build a major observatory in the Southern Hemisphere, and stressing the antiquated condition of the institution's Mount Wilson Observatory. Maybe that letter was influential. For whatever reasons, in May 1963 the trustees approved funds for undertaking a Southern Hemisphere site survey.

Horace credited the trustees with initiating the plan, but Allan Sandage remembers a different scenario. Allan recalls being dragged by Horace into Bowen's office as early as 1961. On these occasions Horace would plead the case for constructing a Southern Hemisphere observatory. Allan's part would be to argue the scientific merits of the case. Early on, Bowen declined to support such an idea, saying that he already had enough to do in running Palomar. Sometime around 1962, as Allan recalls, Bowen changed his mind, and authorized Horace to initiate the development of instrumentation that Horace felt would be needed in conducting a site survey.

Considering that Horace had already begun tests of his seeing monitors in 1962, it is difficult to avoid the conclusion that, as Sandage recalls, Babcock had a much larger and earlier influence on the inception of the Carnegie southern observatory project than he ever claimed, or is generally credited for. In any case, the idea suited Horace's fancy and, as it turned out, his fearsome tenacity was a key factor in bringing the project to a successful completion.

Four ASMs were built, and by the end of December 1963 Horace had taken two of them to Chile to establish surveys on various peaks. A third ASM went to New Zealand and a fourth went to Australia.

A lot happened in the 14 months that followed Horace's appointment as director designate, even before he actually assumed the directorship. There was no time to waste, because two other organizations were also moving to establish major observatories in Chile: ESO (the European Southern Observatory, a consortium that included Holland, Belgium, Germany, Italy, and France) and the U.S. academic consortium known as AURA (Associated Universities for Research in Astronomy). By 1963 AURA had purchased a 180-square-mile tract of land about 50 miles to the east of the city of La Serena and was engaged in developing the Cerro Tololo Inter-American Observatory (CTIO).

The AURA land includes several major peaks, the largest being Cerro Tololo, Cerro Morado, Cerro Pachon, and Cerro Cinchado. AURA's planning initially called for development of only Cerro Tololo, leaving the remaining peaks—especially Morado—open for possible future use by other organizations. Carnegie became one of those organizations considering the use of Morado for the proposed 200-inch telescope. The Europeans had purchased a similarly large tract of land at Cerro La Silla, about 100 miles north of Cerro Tololo, some 20 miles south of the location Horace later chose for Carnegie's observatory (Las Campanas). Horace was in contact with all of these organizations, especially AURA. He loved the outdoors and in the course of time made a close study of the entire Norte Chico region of Chile, where these sites are located.

In February 1964 Horace and Edward Ackerman (Carnegie's executive officer and one of Horace's closest allies in the founding of Las Campanas) trekked on horseback to the summit of Cerro Pachon near Cerro Tololo. They left behind a small team to make continuing seeing observations on Tololo and Pachon. Then in April 1964 Horace sailed to New Zealand and Australia to initiate site surveys there as well. Horace and his colleagues soon concluded that the best sites of all were those to be found in Chile.

By August 1963 an agreement had been signed between the Carnegie Institution and the University of Chile for conducting a site survey in Chile. By November 1963 a proposal had been written for the construction of a Carnegie 200-inch telescope for the Southern Hemisphere. This was soon accompanied by plans worked out by Horace and his engineer, Bruce Rule, for the development of Cerro Morado as a Carnegie observatory site, with detailed plans for roads, housing, water systems, electric power, and so on.

The quest for funding to build a Carnegie 200-inch telescope in Chile is a story unto itself. The quest occupied Horace and his closest associates, especially Ackerman, for at least three years beginning in 1963. An agreement between Carnegie and AURA for development of a Carnegie observatory on Cerro Morado was contingent upon Carnegie receiving a firm commitment for such funding within 24 months of the date of the agreement (that is, by March 9, 1968). Otherwise the agreement would lapse. Horace and his staff and the Carnegie Institution's officers had high hopes that the Ford Foundation would provide the necessary funds to build Carnegie's Southern Hemisphere 200-inch telescope, but by the end of 1966, it had become clear that Ford Foundation funding for a Carnegie southern 200-inch telescope would not be forthcoming soon, if ever. Horace was not deterred.

In 1966 while all this was playing out, Bowen received the prestigious George Darwin Award of the Royal Astronomical Society, and in October delivered his George Darwin lecture titled *Future Tools of the Astronomer*, in which he opined that survey telescopes with large fields of view would be important for the future of observational astronomy. At Horace's urging Bowen began to think about a survey telescope for the Carnegie Southern Observatory. His ideas later evolved into the 40-inch and 100-inch telescopes that were actually built.

A pivotal meeting of the Carnegie staff was held at Carnegie's Santa Barbara Street offices on June 7, 1966. The attendees were Robert Kraft, Olin Wilson, Armin Deutsch, Allan Sandage, Henrietta Swope, and Arthur Vaughan, with Horace chairing the meeting. Horace explained to the staff that Carnegie trustees had earmarked $2 million for a joint Carnegie-Caltech astronomy building on the Caltech campus, but that if a decision could be reached to proceed with a southern observatory, the institution might have a serious problem in providing its share of the funding. Horace polled the staff and reported to Ackerman: "The Observatory staff is firmly of the opinion that, if necessary, construction of a new headquarters building in Pasadena should be postponed in order to assure funding of the CARSO (Carnegie Southern Observatory) project." Furthermore, "If construction of a 200-inch proves impossible in the near future, we should … make an early beginning with the largest and best instrument that can be built with available funds… Bowen's design for a wide-field 85-inch telescope should be explored." This expression of priorities by the Carnegie staff dealt a mortal blow to plans for a new astronomy building at Caltech, and was received with dismay by campus astronomers.

The negotiations with officials of AURA for a Carnegie observatory site at Cerro Morado dragged on for some two years after funding for a Carnegie 200-inch had failed to materialize. AURA's position was that the Morado site would remain under AURA ownership but leased to Carnegie, and the lease would be limited to an area of some 92 acres, far too small to accommodate the array of large telescopes Horace envisioned. Horace washed his hands of that option.

Meanwhile the site survey work continued. Babcock and John Irwin, who ran the site testing program in Chile, summarized their conclusions in an unpublished memorandum:

> In 1968 it became clear that Las Campanas came closer than any other site in meeting the prescribed CARSO criteria: 29 degree S latitude; 7500-8300 feet elevation, with ample space for many telescopes; only 40 miles from the coast and well-separated from the cordillera; good topography, with no mountains to windward; no prospect of future light pollution; easy road construction; ready availability for purchase; and, as confirmed by test wells, adequate water sources.

In September 1968 Horace wrote to Ackerman that in view of the lack of substantial progress in his attempts to deal with AURA, he [Babcock] proposed informally that Carnegie should promptly review the possibility of locating on Las Campanas instead of Morado. This proposal was approved, and Morado was abandoned.

On November 19, 1968, Horace met with Eduardo Frei, the President of Chile, in Santiago and received approval to purchase Las Campanas. President Frei said that he was strongly interested in the project and that it had his cordial support. . . He inquired whether Horace was having any particular difficulties in our negotiations and, following some discussion, Frei telephoned the minister of land requesting that he give Horace all possible assistance. At meeting's end President Frei assured Horace, "The land is yours." It is a big piece of land (50,000 acres, 84 square miles at purchased price for about 30 cents an acre. Not all of that area is suitable for supporting telescopes, but choice sites for additional telescopes lie along a long ridge extending from Cerro Las Campanas northward past Cerro Manqui, site of the Magellan Telescopes, to Cerro Manquis, where the du Pont Telescope is located. The surrounding land area affords a generous buffer against future sources of interference.

Shirley Cohen's interview of Caltech's James Westphal (at website http://oralhistories.library.caltech.edu/107/01/OHO_Westphal_J.pdf, particularly pp. 71-74) contains a fascinating alternative account of some events that preceded purchase of the Las Campanas property. Horace had enlisted the assistance of Westphal, whom I can best describe as Caltech's 20th-century Renaissance man because of his broad laboratory and field experience, and his facility in matters of engineering, electronics, and astronomy.

With the purchase of the Las Campanas property, Horace had the land but not the funds to develop it or to build telescopes. Among Horace's papers Vaughan found a handwritten note dated April 13, 1970: "Dr. Haskins telephoned me today to say that . . . the (du Pont) family is seriously considering closing out one of its foundations. . . Dr. Greenewalt would like to see the assets go to the Southern Observatory." Crawford Greenewalt was at that time president of E. I. du Pont de Nemours and Co., and his wife, Margarita, was the daughter of the late company president and chairman Irénée du Pont. The upshot of all this was that Horace Babcock and Allan Sandage met with Mrs. Greenewalt at Carnegie headquarters in Washington to answer questions she posed. The conversation must have been productive, because the Greenewalts donated $1.5 million toward the construction of "a 60-inch or larger telescope, the balance of its cost to be provided by the Carnegie Institution." In December 1970 the trustees authorized the construction at Las Campanas of a 100-inch telescope, to be named after Mrs. Greenewalt's father. After seven years of traveling, testing, and talking, Horace aided by only a few close associates had finally set Las Campanas Observatory on its course.

Soon thereafter, Horace created the Las Campanas Observatory Committee, which included Bruce Rule as chief engineer, Ed Dennison in charge of electronics, J. B. Oke (Caltech) responsible for auxiliary instruments, Art Vaughan responsible for optics, and Bruce Adkison responsible for administration in Chile, with Ira Bowen serving as consultant. Horace chaired the committee. The first meeting was held on January 20, 1971. Horace's notes documenting the 36 or so Las Campanas Observatory Committee meetings held over the next five years (through January 1976) provide a detailed record of the course of the project.

Site development at Las Campanas proceeded under increasingly difficult conditions. Chile in the 1970s was wracked by severe inflation, political tensions, strikes, and other disruptions, including the assassination of Salvador Allende in Santiago in 1973. Schedule delays and cost overruns brought Horace into conflict with increasingly grumpy officials of the Carnegie Institution of Washington.

Through all of these vicissitudes Horace endeavored to keep the scientists on his staff informed about the status of the Las Campanas Project, while protecting their freedom to remain focused on research. For the most part the scientists paid little attention to the project, until shortly before the du Pont telescope was to be dedicated in late 1976, when the impact of having to staff and operate a new observatory could not be ignored.

The Swope 1.0-meter and du Pont 2.5-meter telescopes built in the 1970s were only the first steps in the development of the major observatory Horace Babcock had envisioned when he became director in 1964. Thanks to the continuing efforts of succeeding generations of Carnegie astronomers following in Horace's footsteps, Las Campanas is now the site of the two superbly engineered 6.5-meter Magellan telescopes, operated by a consortium consisting of Carnegie Institution of Washington, University of Arizona, Harvard University, Massachusetts Institute of Technology, and University of Michigan. And with installation of the Polish 1.2-meter OGLE (Optical Gravitational Lensing Experiment) telescope and the University of Birmingham (U.K.) automated solar oscillation telescope, the Las Campanas operation has taken on an international flavor.

Horace enjoyed the opportunities that came his way for interacting with folks at the working level in the Las Campanas Project. He spoke their language. They appreciated his encouragement. The Las Campanas Observatory that grew out of Horace's vision represents a supreme asset in the hands of the astronomers who use it today. Its value lies not only in the quality of its dark skies and exquisite seeing but also in its infrastructure, including roads, water resources, and geographical expanse suitable for accommodating the largest telescopes currently foreseen. This asset is Horace's legacy, for which he deserves lasting recognition and thanks.

Horace's efforts at Las Campanas perturbed relations among astronomers in Pasadena in several ways. First, the decision to create Las Campanas Observatory was viewed with dismay by some Caltech astronomers, most notably by Jesse Greenstein, who worried that the new facility would put Carnegie and Caltech into a competition for foundation money in which both institutions would lose. Jesse would have preferred to see the Carnegie Institution invest its astronomical resources at Palomar Observatory, so that it could better compete with well-funded national (AURA) and international (ESO) facilities. Furthermore, the relatively modest aperture of the 100-inch du Pont telescope did little to redress the imbalance between Carnegie and Caltech facilities. Beyond that, I believe there was a general perception among Caltech astronomers in the 1970s that Babcock was primarily a Carnegie director, who devoted far too much of his effort to Las Campanas, and virtually none to fund raising and scientific administration for the improvement of Palomar. Such feelings began to erode the collegial foundations of the joint operation of Hale Observatories. Worries about this erosion, in turn, created concern among some Carnegie astronomers, who feared that collapse of the Hale Observatories would endanger their access to the 200-inch telescope. Such issues may have bothered Horace as well, but they did not weaken his resolve to complete Las Campanas Observatory. Thirty years later these concerns are largely forgotten, indeed unknown to the present generation of astronomers, but they seemed very important in 1975, and they should be acknowledged in considering the impact of Horace Babcock's drive to create Las Campanas Observatory.

CODA

Horace Babcock seldom looked back. He labored long and hard to establish superb empirical foundations of subjects that he had mastered—stellar and solar magnetism—but he never again published a refereed paper on these topics after accepting the observatories directorship in 1964. He worked tirelessly to initiate and oversee completion of Las Campanas Observatory: the infrastructure (access roads, water supply, electrical system, lodge) and the telescopes (1.0-meter Swope and 2.5-meter du Pont), but he never set foot on the mountain after his retirement in 1978. He devoted his postretirement years almost exclusively to topics in experimental instrumentation: optical gyroscopes, adaptive optics, a pneumatic telescope. Such devices were perhaps his first love, and he returned to them.

Horace won worldwide acclaim for his contributions to astronomy. Following his election to the National Academy of Sciences in 1954, he was the recipient of the Henry Draper Medal of the Academy in 1957, the Eddington Medal of the Royal Astronomical Society in 1958, the Catherine Wolfe Bruce Medal of the Astronomical Society of the Pacific in 1969, the Gold Medal of the Royal Astronomical Society in 1970, and the George Ellery Hale Medal of the Solar Physics Division of the American Astronomical Society in 1992. In 2004 Symposium No. 224 of the International Astronomical Union, titled "The A Star Puzzle," convened in Poprad, Slovakia. A session held on the first evening of the symposium was devoted to memorial presentations about Vera Khoklova, a Russian astrophysicist who died in 2003, and about Horace Babcock.

Horace was a reserved man who seemed to measure his words on most occasions. He was ill at ease in public situations. He was steadfast, even obdurate, in the execution of his plans for Las Campanas. On the lighter side, Horace enjoyed the sea, and from time to time he relaxed on a 26-foot sailboat that he kept in a slip at Redondo Beach, California. On more than one occasion he invited Pasadena astronomers to accompany him on weekend excursions to the Channel Islands. As one might expect, his boat was equipped with an autopilot of his own design. And, of course, the autopilot took its directions from the earth's magnetic field.

Following retirement Horace continued to work quietly in his office at Santa Barbara Street until 1998, when he moved to a retirement community in Santa Barbara to be near a son. He died 15 days short of his 91st birthday in 2003 and was buried in the family plot at Mountain View Cemetery in Pasadena, following a simple graveside gathering of family and friends, at which his children in turn reminisced about their father. Horace is survived by his children: Ann L. and Bruce H. by his first marriage, and Kenneth L. by a second marriage, to Elizabeth Aubrey (divorced).

IN PREPARING THIS MEMOIR I borrowed from presentations of Donald Osterbrock and Arthur Vaughan delivered at the Babcock Memorial Symposium held at Caltech on May 21, 2004. I also referred extensively to the American Institute of Physics oral interview of Horace conducted by Spencer Weart on July 25, 1977. Some of my remarks are based on personal recollections.

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