NATIONAL ACADEMY OF SCIENCES

JESSE LEONARD GREENSTEIN
1909–2002

A Biographical Memoir by

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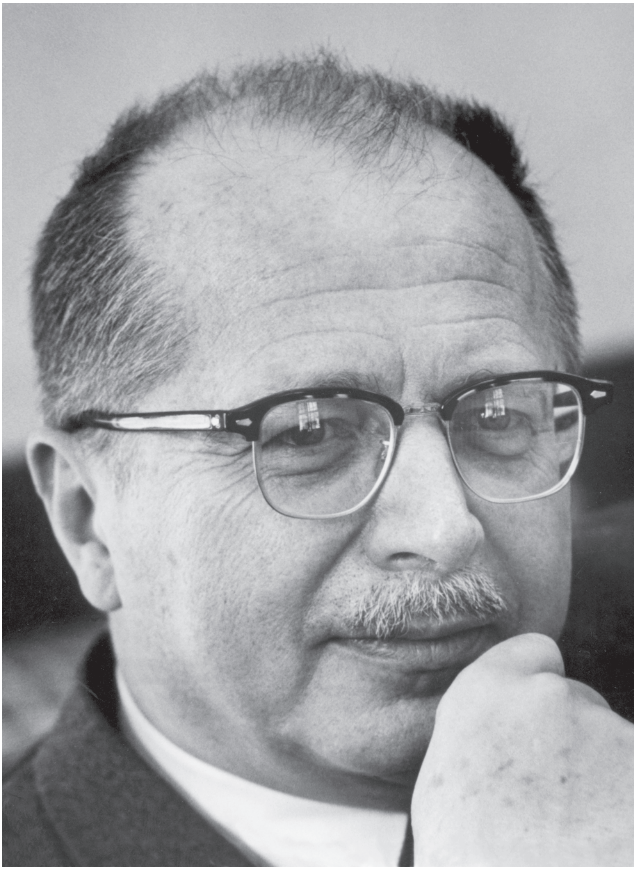
Biographical Memoirs, VOLUME 86

PUBLISHED 2005 BY
THE NATIONAL ACADEMIES PRESS
WASHINGTON, D.C.



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JESSE LEONARD GREENSTEIN

October 15, 1909–October 21, 2002

BY ROBERT P. KRAFT

JESSE L. GREENSTEIN WAS born and raised in New York City. He received advanced degrees from Harvard University just before and during the Great Depression. As a graduate student he made pioneering advances in understanding the influence of interstellar dust on the colors and magnitudes of stars. Studies of the nature of interstellar dust continued as he moved westward in post-Harvard years, first to Yerkes Observatory and later Caltech, where he developed the analysis tools and founded a program of study devoted to the determination of the chemical abundances in stars, a field in which he became the world's observational leader. His work on a wide array of problems ranging from the properties of QSOs (quasi-stellar objects), the nature of interstellar grains, the evolution of the chemical composition of stars, to the physical properties of white dwarfs provides the currently available fundamental knowledge of each of these fields. He was a leader of U.S. astronomy, and his advice, heeded by both universities and government agencies, shaped the present organization of astronomy as it is conducted in the United States.

THE EARLY YEARS

Jesse was born in New York City in the year of Halley's comet. His grandfather Samuel Greenstein had emigrated to America in 1888, leaving behind in Bialystok (now in Poland, but then part of Russia) his wife and two small children. He prospered in the manufacture of living-room furniture and brought the family to New York when Jesse's father, Maurice Greenstein, was two years old. On grandfather's death, Maurice, the oldest of nine children, assumed leadership of the business. As had his father before him, Maurice bought real estate in Brooklyn as well as Manhattan, and he and the other members of the family eventually became quite prosperous. In 1908 Maurice married Leah Feingold, who had been working as a stenographer in the furniture factory founded by his father. Jesse was born in the following year.

Jesse often described his upbringing in the folds of a typical upper-middle-class Jewish family of the period as "indulgent." In an unpublished memoir he recounts his early interest in both science and the arts. When Jesse was eight years old, his grandfather gave him a small brass telescope with which he regaled his friends with the wonders of the heavens. The contemporary semipopular books on astronomy were available to him, thanks to his grandfather's excellent private library. In grandfather's basement laboratory Jesse set up a Gaertner prism spectroscope, electric arc, rotary spark gap, and a rectifier from which he tried to identify, with some success, the spectral lines of chemical elements, using Kayser's *Handbook of Spectroscopy* as a resource. It was a harbinger of Jesse's main research interest after his move to Caltech 30 years later.

At the age of 11 Jesse was enrolled in a private high school, the Horace Mann School for Boys, where he learned

Latin as well as the "virtues," as he put it, of "hard work." Chemistry fascinated, but the classical physics curriculum of statics and levers he found of little interest.

HARVARD UNDERGRADUATE YEARS, THE GREAT DEPRESSION

Jesse entered the Harvard astronomy program at the tender age of 15. In the mid-1920s the program still retained its classical roots, with emphases on transit circles, navigation, and celestial mechanics, and it was not until 1928-1929 that Jesse came into contact with faculty members of the Harvard College Observatory, an administratively separate entity. There he learned of the new developments in astrophysics and galactic structure under the influence of such figures as the young Canadian theorist Harry Plaskett; Donald Menzel, whose interests were in solar physics, gaseous nebulae, and atomic processes; and especially Cecilia Payne, an English astronomer whose thesis "Stellar Atmospheres" Jesse described as "one of the great theses in astronomy." His undergraduate education was diffuse, but included a course in the philosophy of science and an introduction to what one of his professors termed the new fad of quantum mechanics.

On graduating in 1929 Jesse was offered a postgraduate appointment at Oxford by E. A. Milne, a British theoretician whom he had met during Milne's visit to Harvard. But a bout with a throat infection prevented Jesse from accepting the appointment, and he remained at Harvard, taking a master's degree in 1930. As Jesse himself has noted, loss of this opportunity was "just as well"; his interests throughout his subsequent career lay not so much in developing the computational skills of a serious theoretician as in understanding the basic physics underlying astronomical phenomena.

The period just before and immediately after the October 1929 stock market crash was for Jesse, the scion of a well-to-do family, a time not only of serious astronomical study but also a time for indulgence in modern art, fashionably avant-garde literature, and adventures in the theatre, not only in the Boston area but also in New York itself. All this came to an abrupt end in 1930 as Jesse left Harvard for home, M.A. in hand, to help rescue the failing fortunes of the family business. It was a time to come to grips with reality, to deal with financial losses, to learn how to manage difficult social relationships emerging from the Depression. But fate intervened on the side of science; at a dinner party Jesse met the outstanding Columbia physicist I. I. Rabi, who encouraged him to leave the real estate business and re-embark on his scientific career. Rabi introduced Jesse to Jan Schildt, a Columbia professor who had returned from Mt. Wilson in 1926 with several direct photographs of the globular cluster M3, and he made this material available to Jesse as a "volunteer." With his practiced Harvard eye Jesse measured magnitudes and derived periods for M3 RR Lyraes. Although the work was monotonous, it convinced Jesse that his real love was astronomy, not the attempt to make money in the real estate business, even though by 1934 he had already made a very lucrative real estate deal.

Jesse, now confident of his future course, returned to Harvard graduate school, despite the warning of Harlow Shapley, the Harvard College Observatory director, that astronomy had changed too much for Jesse to catch up. In the meantime Jesse had married Naomi Kitay on a snowy day in January at her home in New Jersey. Jesse had met Naomi as early as 1926. A young woman of wide interests in literature, the arts, and especially theatre, Naomi was fluent in French and had traveled widely in Europe. She had graduated from the Horace Mann School for Girls, and from Mt. Holyoke College in 1933. The author remembers Naomi as the charming hostess of soirees in the Pasadena home of the Greensteins; Jesse referred to her in conversation as "Kitty," obviously a term of endearment derived from her family name.

RETURN TO GRADUATE WORK AT HARVARD

On returning to Harvard College Observatory (HCO) Jesse found a much-changed atmosphere, with graduate study being dominated by a group working on the physics of ionized gases under Menzel and another under Bart Bok counting stars as a technique for studying galactic structure. Completing his course work in a scant two and one-half years, Jesse returned for his Ph.D. thesis to a problem that had vexed him as an undergraduate: the influence of interstellar dust on the colors and magnitudes of early type (B) stars. Thanks to the work of R. J. Trumpler at Lick, it was by 1934 pretty well accepted that interstellar space was filled with clouds of dust that not only dimmed but also reddened the colors of stars. On the basis of low-resolution objective prism spectra obtained with the resident Harvard 24-inch telescope, Jesse measured photographically the energy distributions of little and greatly reddened B-type stars (difficult to do accurately with the techniques available in the 1930s), and showed not only that absorption by dust followed a $\lambda^{-0.7}$ law but also that the slope was essentially independent of the choice of interstellar cloud (i.e., the law appeared to be universal). In a difficult series of calculations based on Mie theory, Jesse examined the absorption produced by small grains of water ice, silicates, and metals, showing that for appropriate choices of composition and grain size distribution, the observed law, so different from the Rayleigh scattering of the earth's atmosphere, might be reproduced. These pioneering observational results were confirmed later by more accurate photoelectric techniques (of J. Stebbins and A. Whitford), and the calculations provided a basis for a more definitive treatment (by C. Schalen) along the same lines.

With Fred Whipple, then an instructor at HCO, as a collaborator, Jesse noted K. Jansky's startling discovery of cosmic radio noise from the direction of the galactic nuclear bulge, and the two of them attempted to explain the phenomenon as the result of thermal emission from the heavily obscuring dust clouds in and around the galactic center. Although the explanation failed to give the correct answer by several orders of magnitude, the attempt highlights salient features of Jesse's scientific outlook. One was his intellectual curiosity. Few astronomers of the time took an interest in Jansky's discovery (although, to be fair, it had been published in an engineering journal not generally read in the astronomical community), but Jesse and Fred Whipple found it exciting and tried to explain it using the best theoretical notions of the time. In addition, Jesse's recognition of the new world opened up by this discovery was the spark that ignited his support of radio astronomy at Caltech some 20 years later.

TRANSFER TO YERKES (AND MCDONALD), WORLD WAR II YEARS

On graduation Jesse accepted a National Research Council Fellowship for 1937-1939, a rare opportunity in those days, and chose Yerkes Observatory of the University of Chicago as host institution. As Yerkes was located in a tiny Wisconsin town surrounded by farmland, one might wonder why a city boy would chose such a place, but Yerkes was then entering an intellectual golden era. First, in contrast with the almost purely observational orientation of Lick and Mt. Wilson, Yerkes was an observatory that welcomed theoretical astrophysicists both as staff members (e.g., S. Chandrasekhar) and as visitors (e.g., A. Unsöld and K. Wurm). Second, the organization was undergoing staff expansion, preparing for the inauguration of the 82-inch telescope of the McDonald Observatory, located in the superior climate of the Davis

Mountains of west Texas. Finally, Yerkes was moving forward under the dynamic leadership of Otto Struve, an observational astronomer well versed in the new astrophysical spectroscopy, a man whom Jesse had greatly admired when Struve visited Harvard during Jesse's years as a graduate student. It was the kind of intellectual atmosphere that appealed to the young Jesse Greenstein. Then, too, the appointment might provide an opportunity to mount an observational program with the new facilities at McDonald.

In addition to Struve and Chandrasekhar, Jesse met such important figures as Gerard Kuiper, Bengt Strömgren, and W. W. Morgan. He soon developed a friendship and scientific collaboration with Louis Henyey, a recent Ph.D. from Yerkes, a theoretician of formidable mathematical skill, whose interests in gaseous nebulae and interstellar matter paralleled his own. Henyey's Ph.D. thesis had described the physics of interstellar dust in a way that complemented Jesse's own Harvard thesis. Stimulated by a late-night brainstorming session with Struve, the two young researchers built a Yerkes nebular spectrograph of unusual fast design, which—jerry-built for the 40-inch refractor—nevertheless yielded spectacular spectra of the earth's aurora. An improved version of the design was transferred later to a mountainside at the McDonald site and used subsequently by Struve and Strömgren to discover what Strömgren later called "H II regions." Meanwhile, Greenstein and Henyey employed a novel Fabry photometer on the 40-inch and discovered diffuse galactic light, the scattering of light from stars produced by dust clouds in the Milky Way, along lines of sight far from the stars themselves. Although the clouds are essentially opaque in transmitted light, the starlight scattered by them makes the clouds appear bright, indeed, bright enough to require the dust to be more luminous than snow! According to Jesse's thesis the dust was therefore a dielectric having low true absorption, either ice or a silicate, a result that has held up well, although it is not the entire story.

In 1939 at the termination of his fellowship Jesse was appointed an instructor, which allowed him to remain at Yerkes after the dedication of the 82-inch reflector, then the second-largest telescope in the world. Jesse's research took a new turn, partly as a result of Struve's influence and partly as a result of the availability of the brand-new coude spectrograph at the 82-inch reflector. After assisting Struve in obtaining spectra of the standard hot B-type star tau Scorpii for analysis by Unsöld's stellar atmospheres group in Kiel, Jesse went on to obtain similar spectra of upsilon Sagittarii, a star having an unusually peculiar spectrum, which after analysis by Jesse, proved to have a hydrogen-poor, helium-rich atmosphere. A parallel analysis of Canopus, a southern supergiant, yielded normal (i.e., solar-like) abundance ratios of the chemical elements. It is easy to forget now, in our present era of excellent model atmospheres and vast computing power, just how primitive abundance studies were in the late 1930s. Jesse developed the practical side of the so-called method of "grobanalyse," or curves of growth, that had been pioneered by Unsöld and Struve. Transition probabilities came from theory and/or solar line strengths, something of a grab bag, even though the source of solar continuous opacity, H-, had by then been identified. The fact that upsilon Sagittarii did not conform to the expectation that stellar abundance ratios were universal was a major breakthrough in what would become, in the years following World War II, the idea of galactic chemical evolution. The analysis of upsilon Sagittarii thus profoundly influenced the direction that Jesse's research would take in his later years.

Even so, Harvard-influenced projects had not entirely left Jesse's repertoire. The year 1939 saw publication of a color-magnitude array of the relatively nearby globular cluster M4, based on photographic photometry of Harvard plates. The array, with its strange configuration of giants and horizontal branch stars, so different from that of the so-called "open" clusters of the Milky Way, was one of unusually high accuracy and was for the time a particularly fine illustration of those differences. It was yet a decade in the future before Walter Baade would generalize the differences into his two-population concept, and 15 years before the differences were linked to the effects of mass, age, and composition on stellar evolution. Although Jesse never returned to the construction of cluster color-magnitude arrays, his future research would contribute mightily to understanding the chemical composition and age differences between stars in globular and open clusters.

With the advent of U.S. participation in World War II, Struve struggled to keep Yerkes and McDonald telescopes in operation as staff scattered into defense industries and those who remained at Yerkes, Jesse among others, also moved into war work. Consequently Jesse was not drafted; he and Henyey went to work under the auspices of OSRD (Office of Scientific Research and Development), designing lens systems for military application. The two of them produced a number of OSRD reports on military applications of optical design, with titles such as "Unit Power Periscopes," "Tank and Anti-Tank Telescopes," and "Wide-Field Fast Cameras." Working with strange glasses, developing new methods of ray tracing, as well as dealing with industrial and military personnel were new experiences for Jesse. As a junior Yerkes staff member he had not participated in administrative decisions, but the war work initiated him into the world of committee meetings and the responsibilities of management. He was thus prepared for membership on the postwar committee of the Office of Naval Research, which funded small grants for astronomical research projects, in effect, a forerunner of what later would become the National Science Foundation's astronomy program. Jesse's observing runs at McDonald continued as he advanced by 1946 to the rank of associate professor.

THE MOVE UP TO THE 200-INCH TELESCOPE: FOUNDING THE CALTECH GRADUATE PROGRAM IN ASTRONOMY

In June 1948 Jesse arrived in Pasadena, having accepted an offer from Caltech of an associate professorship, with the principal duty of organizing a new graduate program in astronomy and astrophysics. Now a family man with two sons, eight-year-old George and two-year-old Peter, he and Naomi welcomed a return to urban living after 11 years in the remote countryside. The move coincided with the dedication of Caltech's great new 200-inch telescope, to which Jesse would now have access, and which held the promise of unprecedented research opportunities. At the same time, as executive officer of astronomy, a post he held until 1972, Jesse would need to devote a large amount of time to the administrative activity of selecting professorial and research staff for the department, as well as directly participating in the teaching and mentoring of graduate students. Despite these administrative and teaching responsibilities, Jesse chose not to eschew his research programs. He had been author or coauthor of 70 papers by 1948. His output expanded to more than 400 papers by the end of his active career in the early 1990s.

Jesse, who was almost immediately advanced to the rank of full professor, began teaching stellar atmospheres and interiors to physics and new astronomy graduate students, and took up the task of recruiting astronomy faculty. Early appointees included a number of Yerkes Ph.D.s (e.g., Arthur Code, Donald Osterbrock, Guido Münch), all of whom gained fame as prominent research astrophysicists in later years. Thus began the as-yet-untold story of the westward migration of the Yerkes style, which led to the reformation of science as it was conducted in the west coast departments and observatories. Already in 1947 Henyey had left Yerkes for the Berkeley astronomy department, to be followed in 1950 by Struve himself. Bolstering the graduate course offerings at Caltech were the lectures of resident Carnegie-Mt. Wilson astronomers, who became de facto visiting faculty following formation of the joint authority known as the Mt. Wilson and Palomar Observatories. To this mix were added the unique contributions of Fritz Zwicky, who had been already a member of the Caltech physics faculty well before the expansion. The first Ph.D.s in the new program were Allan Sandage, Helmut Abt, and Halton Arp, all of whom became important research figures in later years.

In this milieu in which astronomy was closely coupled in a divisional structure with physics and mathematics, Jesse's research flourished as his penchant for exploring and explaining new phenomena expanded. In collaboration with Leverett Davis, a Caltech physicist with wide knowledge of electromagnetic theory, Jesse returned to his old love affair with the properties of interstellar grains. From studies of the polarization of starlight W. A. Hiltner had shown that the Milky Way was threaded with a weak but highly organized magnetic field. Davis and Greenstein modeled the grains as elongated and rapidly spinning, and predicted the field should lie along the spiral arms of the galaxy, as observed.

THE ABUNDANCE PROJECT

By 1952, I. S. Bowen, the first director of the Mt. Wilson and Palomar Observatories, had completed construction of the innovative 200-inch coude spectrograph, and using this instrument, Jesse returned to the study of relative abundances, particularly in stars with abnormal spectra such as carbon stars and metallic-line A-type stars. Stimulated by friendship with William A. Fowler of the Caltech Kellogg Radiation Lab as well as the 1956 predictions of the stellar origin of the heavy elements by Fowler and colleagues Fred Hoyle and Margaret and Geoffrey Burbidge, Jesse obtained funding from the Air Force Office of Scientific Research for the famous Abundance Project, which spanned the period from 1957 to 1970. The grant supported not only Jesse's observational program with the coude spectrograph but also a substantial analysis team of graduate students and postdocs, many of whom became prominent figures in today's astronomical world.

Advances in the theory of stellar evolution initiated by Sandage and Martin Schwarzschild and continued principally by Icko Iben, coupled with the corresponding interpretation of globular and open cluster color-magnitude diagrams by Sandage, Arp, Harold Johnson, and others, led to the conclusion that globular clusters and other halo stars must be older than the sun and much older than stars of open clusters. These results set the stage for the study of stellar abundances as a function of time since the big bang. The Abundance Project was thus at the heart of the quest to delineate galactic chemical evolution. Perhaps the most exciting of the early papers is one by H. L. Helfer, G. Wallerstein, and Greenstein in which it was shown conclusively that globular cluster giants had metal abundances as much as two orders of magnitude below that of the sun (relative to hydrogen). Using the photographic plates of the day, with their 1 percent quantum efficiency, obtaining spectra of even the brightest globular cluster stars represented a monumental task: Exposure times for a single star usually required more than one night, even using the 200-inch telescope coupled to Bowen's state-of-the-art coude spectrograph.

There followed a series of papers that established that halo field giants and subdwarfs, i.e., stars usually identified as having kinematics (proper motions and radial velocities) associated with the galactic halo, had metal deficiencies similar to those of globular cluster giants. Generally such objects proved to have subnormal ratios of the heavy elements (e.g., Sr, Y, Ba, Eu) to the common metals such as Fe. On the contrary, oxygen and the elements containing an even number of alpha particles (e.g., Mg, Ca, Ti) were found to be overabundant relative to Fe. Another paper showed that stars in the Hyades, a cluster much younger than the sun, nevertheless had compositions similar to that of the sun. Those taking part in these studies included colleagues such as Lawrence Aller (who had been a pioneer in showing the existence of stars with metallicities below that of the sun) and several postdocs who became notable figures in the astronomical world: Helfer and Wallerstein, already mentioned, along with G. and R. Cayrel, W. Sargent, P. Conti, H. Spinrad, A. Boesgaard, V. Weidemann, B. Baschek, J. Jugaku, and R. Parker, among others. A paper by Jesse and Wallerstein devoted to an analysis of two metal-poor halo giants known as CH-stars showed that these were not only carbon-rich but also were seriously overabundant in heavy elements such as Ba, La, and Ce, totally unlike the situation with the common metal-poor stars of the halo. All these results provided the observational testing ground for theories both of stellar structure and evolution and for scenarios on the origin of the chemical elements in the post-big-bang era.

RADIO ASTRONOMY, QSOS

Harking back to his 1937 collaboration with Fred Whipple in the abortive attempt to explain Jansky's newly discovered radio noise, Jesse retained his fascination with radio astronomy and, beginning in 1956, helped to organize Caltech's Owens Valley Radio Observatory. Most of the rest of the optical astronomy community had remained fairly indifferent to the postwar development of radio astronomy, until it was discovered in 1951 that a powerful radio source was associated with Cygnus A, a strange galaxy thought to be, in fact, two galaxies in collision. By 1954 many weaker radio sources were discovered, some identified with optical galaxies, some possibly with blue stellar objects, but lack of angular resolution at radio wavelengths led to significant uncertainties in optical identification.

In the same year Jesse organized a conference at Carnegie headquarters attended by radio astronomers from around the world, plus optical astronomers such as Jesse himself and R. Minkowski, as well as Lee DuBridge, then president of Caltech. Out of this meeting arose the founding not only of Owens Valley Radio Observatory but also the National Radio Astronomy Observatory. DuBridge with Jesse's strong support then invited John Bolton, an Australian radio astronomer, to set up Owens Valley and start the Caltech radio astronomy program. Owens Valley was dedicated in 1958 and quickly became one of the premier observatories of its kind.

Jesse's interest in radio astronomy soon crossed paths with another of his new interests—faint blue stellar objects—in an unexpected way. Stars with very blue colors were known to be a varied lot; some were halo horizontal branch stars, others white dwarfs, and still others cataclysmic variables such as old novae. Meanwhile, some strong radio-emitting objects that had been found in the Cambridge radio survey were clearly identified with active galaxies. Jesse took an interest in the subset of radio emitters that appeared to be stellar and that exhibited blue continua crossed by a few weak emission lines. The object called 3C48 was a good example; its few rather broad emission lines defied certain identification. The anomaly cleared up when Maarten Schmidt discovered the unmistakable signature of the hydrogen Balmer series in 3C273, a blue starlike radio source, of which an accurate position had been obtained by means of a lunar occultation. Amazingly, the hydrogen lines of 3C273 were redshifted by 16 percent. In consultation with Schmidt, Jesse realized that the lines of 3C48 could be identified with emission lines of [O I], [NeIII], and [NeV] redshifted by 37 percent. As Jesse himself has noted, the "logjam was broken." In a landmark paper Greenstein and Schmidt (1964) discussed the physics of the emitting region in these two objects, rejected the notion that gravitational redshifts could explain what was seen, produced evidence in support of the idea that the redshifts were cosmological, and noted the impossibility of a nuclear energy source as an explanation of the extraordinarily high luminosities required. Aside from a student study of the radiation from M31, this was Jesse's only foray into extragalactic astronomy. Having participated in the breakthrough physics of understanding QSOs, Jesse was content to leave the remaining mysteries for others to solve. It was entirely characteristic of his scientific style.

LATE RESEARCH: WHITE DWARFS, RED DWARFS

Beginning around 1965 and on into his post- (de jure) retirement years, Jesse's taste for conquering new horizons led him to an intensive study of white dwarfs, the last stage of evolution of stars with masses less than about 8 M(sun). They are a unique subset of the kind of blue stellar objects that had already piqued Jesse's interest. Observing these intrinsically as well as apparently faint stars presented a formidable task even for the 200-inch telescope; the lines are weak, often diffuse, and low spectral resolution is required if one is to have sufficient signal to noise. Until he retired from active observing in 1986 Jesse provided fundamental data for 550 white dwarfs, using the prime focus nebular spectrograph, later the multichannel spectrometer and double CCD spectrograph constructed by his faculty colleague J. B. Oke. Early in this period he and Olin Eggen (1965-1967) turned out spectral classifications, colors, luminosities, and space motions for 200 white dwarfs. With Virginia Trimble he derived the mean mass of white dwarfs (0.6 Msun) from the K-term in their motions and the corresponding gravitational redshift. In over 60 papers spread over 20 years Jesse explored such additional topics as surface composition, energy distribution, line profiles, magnetic fields, rotation, gravitational diffusion, and cooling theory for white dwarfs. Accurate energy distributions plus models led to an accurate temperature scale. The well-known so-called "DA" white dwarfs were shown to have essentially no helium and virtually no metals, whereas non-DAs were shown to have no hydrogen but rather small amounts of carbon and metals. Many of these atmospheric abundance puzzles were found to be a result of gravitational diffusion rather than real abundance anomalies. Of more than usual interest was the discovery in one star of a seriously displaced Lyman-alpha line, resulting from a dipole magnetic field of 350 megagauss! Jesse also showed that white dwarfs have very small angular momentum, meaning that in the course of evolution, their predecessors must lose not only mass but relatively more angular momentum presumably in magnetically coupled winds. In short, Jesse's work provided the essential backbone of all we presently know about white dwarfs. Near the end of his active career Jesse made excursions on the other side of the subject of intrinsically faint stars, with adventures in trying to detect faint M dwarfs and exploring the properties of candidate brown dwarfs. With Jesse there was always a new stellar astronomy field to conquer.

SCIENTIFIC STATESMAN

During his Caltech years, Jesse's advice was sought by many university groups and government agencies responsible for overseeing the growth of support for science in the post-World War II era. He served on some 50 different committees at various times in this period. Space does not permit an exhaustive listing, but a few of the important ones follow. He was a member of the Committee on Science and Public Policy of the National Academy of Sciences, advised NASA on such matters as the scientific management of the Space Telescope (which ultimately led to the establishment of the Space Telescope Science Institute), served on the Board of Overseers of Harvard University, and was chairman of the Board of Directors of the Association of Universities for Research in Astronomy, the managing entity of the National Optical Astronomy Observatories.

Probably of greatest importance to astronomers was his acceptance to be the chairman of the second decadal review of astronomy, the results of which are published in *Astronomy and Astrophysics for the 1970's*, more generally known as the Greenstein Report. Following on after the initial study of this kind, the Whitford Report of 1964, it was a response to the demand of the federal funding agencies for a prioritized list of future possible astronomical facilities and associated costs. Except for planetary missions, the Greenstein Report considered all of astronomy, ground-based (IR, radio, optical, solar), space (X and gamma rays), as well as theoretical astrophysics, dynamical astronomy, planetary astronomy, and statistical studies. Out of the panel discussions and further evaluations arose a rank-ordered list of priorities, with the VLT (Very Large Array) of radio telescopes, constructed ultimately in New Mexico, topping the list.

The period marked the end of an era, especially in ground-based astronomy, in which observational work had been dominated exclusively by private or semiprivate organizations in which access to facilities was restricted to local staff members. Facilities open to all qualified scientists on a competitive basis were now being funded with federal dollars. Having spent his career in the private observatory sector, Jesse quite naturally defended the idea that the private sector deserved federal support, too. He felt strongly that the future of astronomy lay in the kind of large-scale observational programs that could be mounted by brilliant and dedicated staff having virtually unlimited telescope access. But this outlook did not prevent Jesse from supporting the federal capitalization of public projects, even those that seemed contrary to more parochial interests. Marshall Cohen, Caltech professor emeritus, has recalled his experience with Jesse's leadership when he was a member of the Radio Panel in the 1970 decadal review.

> At one point the panel members had a serious disagreement over the recommendation for the next large radio astronomy facility. Caltech, MIT and the National Radio Astronomy Observatory (NRAO) all had plans, they were mutually exclusive, and no one would give in. Jesse demanded that the panel pick one instrument for the Report, and finally we picked the NRAO proposal, which later was funded and became the VLT, an extremely important telescope. In this process Jesse was above institutional concerns, and while he would have been pleased if the Caltech proposal had been chosen, he did not push me or the Caltech proposal. In this and other ways, he was a national servant.

HONORS AND HONORIFIC OFFICES

In recognition of his scientific accomplishments and services to astronomy, Jesse was elected to many scholarly organizations including the National Academy of Sciences (in 1957), the American Academy of Arts and Sciences, the

American Philosophical Society, the Royal Academy of Sciences (Liege), and was elected an associate of the British Royal Astronomical Society. Honors included the California Scientist of the Year award in 1964, the Henry Norris Russell Lectureship of the American Astronomical Society in 1970, the Bruce Medal of the Astronomical Society of the Pacific in 1971, the NASA Distinguished Public Service Medal in 1974, and the Gold Medal of the Royal Astronomical Society in 1975. He received an honorary D.Sc. from the University of Arizona in 1987. At various times he was a visiting professor at Princeton, the Institute for Advanced Study, NORDITA (Copenhagen), and the University of Hawaii and was appointed Lee DuBridge Professor of Astrophysics at Caltech in 1970, a post he held into his (de jure) retirement years. He was honored at several international symposia dedicated to fields in which he worked, in recognition of his sixtieth, seventieth, and seventy-fifth birthdays.

SOME PERSONAL REMINISCENCES

I was not an insider and knew Jesse mostly from a distance. But we did share a seven-year collegial period (1960-1967) as staff members of the Mt. Wilson and Palomar Observatories, he at Caltech, I at Carnegie on Santa Barbara Street. I consulted with him occasionally on scientific matters, but as a junior staff member I played no role in the administrative activities and thus saw no part of Jesse in that theatre of action. As part of the broader observatory group one was invited to attend Friday luncheons at the Athenaeum, where if you were lucky, you might sit at Jesse's large table and be privileged to hear his take on the important astronomical topics of the day. He was a font of knowledge on many topics and loved to work out the basic astrophysics of some new discovery, his pen busy scratching its way on the large paper napkins the Athenaeum regularly provided. He often said that the real fun for him in astronomy was learning the physics (new to him!) required to explain some new astronomical phenomenon. He was not interested in routine activities. Jesse maintained his love of spectroscopy as the fundamental observational tool of astrophysics. From time to time he would utter a kind of mantra. “Spectroscopy is the queen of astronomy,” he would say. Regrettably, I never thought to ask him who or what was king!

Jesse maintained a collection of spectrograms of old novae, since these fell in the category of faint blue stars (in their postexplosive stage). He was especially fond of the old nova called WZ Sagittae, because its spectrum contained not only the characteristic hydrogen emission lines but also the absorption lines of a white dwarf. At one of these luncheons I had just returned from an observing run at Palomar and had discovered that WZ Sagittae was a binary star with an incredibly (for those days) short period of 82 minutes. I had vaguely remembered hearing an arcane (to me) lecture by S. Chandrasekhar on gravitational radiation and wondered whether this old nova might be a candidate for emission of gravitational waves. But where was one to look for information? Jesse knew, as always a font of knowledge. I should look in the book by Landau and Lifshitz and go talk with Jon Mathews in the physics department who knew about such arcane things. In the end, two developments came out of this. Jesse, Mathews, and I wrote a paper on the possibility that WZ Sagittae might emit gravitational energy on an interesting cosmic time scale. A few weeks later there appeared on my desk a package containing Jesse’s complete library of old nova spectra with a note: “Bob, the field is yours now. Here is my collection. Use it well.” It was a demonstration of Jesse’s kindness toward junior scientists.

Earlier, knowing of my interest in old novae while I was still on the Yerkes staff, Jesse wrote asking whether I would be interested in analyzing spectra of nova DQ Herculis, then the best-known old nova (1934), around its 4-hour and 39-minute orbital cycle. Of course I would! Jesse got the spectra with the 200-inch nebular spectrograph and they were amazing; they showed the rotational disturbance through the eclipse, thus proving that the collapsed star was surrounded by an accretion disk. Again Jesse shared with someone much younger the joy of discovery and publication of research. But this was characteristic of the man; of the scores of papers turned out by members of the Abundance Project, Jesse's name almost never appears as the first author. He was content to generally direct and be a major advisor and allow the younger people to have their place in the sun. According to Ann Boesgaard, professor of astronomy at the University of Hawaii and earlier a postdoc in the Abundance Project, Jesse was the first of the old-guard Mt. Wilson and Palomar astronomers to support the work of, and suitable accommodations for, female astronomers at the telescopes, significant progress into what had been an exclusively male-oriented club.

A man of wide cultural interests, Jesse loved classical music, particularly the chamber music of Mozart and Schubert, and especially the late quartets of Beethoven. At Jesse's memorial service, son Peter engaged a string quartet to play the cavatina from Beethoven's Quartet, op. 130, which seemed especially appropriate. During a six-month visit to Caltech in 1980, I learned of Jesse's deep interest in Asian art and was shown some of his collection of Asian treasures. His interest extended beyond collecting, serving as he did on the Board of Trustees of the Pacific Asia Museum from 1979 onward.

Jesse also had an interest in things more mundane. He loved fast foreign cars and once held a Caltech speed record for the trip from Pasadena to Palomar. He enjoyed Bordeaux wines and worried on one occasion whether he should buy a case of a well-known first growth from a good year fearing he might not live to drink it in its maturity. He also loved a brand of small cigar that was especially fragrant; you didn't have to look at the schedule to know whether you were following Jesse in the 200-inch prime-focus cage: There was something in the air!

Naomi Greenstein passed away in 2001 after a long illness. Jesse is survived by his two sons, George, a professor of astronomy at Amherst, and Peter, a librarian and jazz musician working in Oakland, California, and their families. Jesse was one of the great figures of U.S. astronomy in the twentieth century. In this era of multi-authored papers occasionally numbering in scores, he was virtually the last of a vanishing breed, representing a style no longer much with us: the single astronomer alone on a dark night in a cramped telescope cage, exposed and cold, in a personal confrontation with God, or Nature, or the Truth, or whatever you may choose to call it.

I AM INDEBTED TO George Greenstein for valuable family information and to Peter Greenstein for access to his father's extended personal memoir. I thank Prof. Marshall Cohen for his encouragement and permission to quote his experiences as a member of the Radio Astronomy Panel of the 1970 decadal review. Valuable information was also provided by Profs. George Wallerstein and Ann Boesgaard, to whom I am greatly indebted. I thank Don Osterbrock, Marshall Cohen, Peter and George Greenstein, and Ann Boesgaard for reading and commenting on a first draft of the manuscript.

SELECTED BIBLIOGRAPHY

1938

A determination of selective absorption based on the spectrophotometry of reddened B stars. *Astrophys. J.* 87:151-175.

1939

Magnitudes and colors in the globular cluster Messier 4. *Astrophys. J.* 90:387-413.

1940

The spectrum of upsilon Sagittarii. *Astrophys. J.* 91:438-472.

1941

With L. G. Henyey. Diffuse radiation in the galaxy. *Astrophys. J.* 93:70-83.

1942

The spectrum of alpha Carinae. *Astrophys. J.* 95:161-200.

1946

The ratio of interstellar absorption to reddening. *Astrophys. J.* 104:403-413.

1949

With L. Davis, Jr. The polarization of starlight by interstellar dust particles in a galactic magnetic field. *Phys. Rev.* 75:1605.

1951

Interstellar matter. In *Astrophysics,* ed. J. A. Hynek, pp. 526-597. New York: McGraw-Hill.

1955

With J. B. Oke. The rotational velocities of A-, F-, and G-giants. *Astrophys. J.* 120:384-390.

1956

With W. A. Fowler. Element-building reactions in stars. *Proc. Natl. Acad. Sci. U. S. A.* 42:173-180.

1959

With L. Helfer and G. Wallerstein. Abundances in some population II giants. *Astrophys. J.* 129:700-719.

1960

With L. H. Aller. The abundances of the elements in G-type subdwarfs. *Astrophys. J.* 5(suppl.):139-186.

Spectra of stars below the main sequence. In *Stellar Atmospheres*, ed. J. L. Greenstein, pp. 676-711. Chicago: University of Chicago Press.

1961

With R. Parker, L. Helfer, and G. Wallerstein. Abundances in G dwarfs. IV. A redetermination of the abundances in G dwarfs in the Hyades. *Astrophys. J.* 133:101-106.

1962

With R. P. Kraft and J. Mathews. Binary stars among cataclysmic variables. II. Nova WZ Sagittae: A possible radiator of gravitational waves. *Astrophys. J.* 136:312-314.

1964

With G. Wallerstein. The chemical composition of two CH stars, HD 26 and HD 201626. *Astrophys. J.* 139:1163-1179.

With M. Schmidt. The quasi-stellar radio sources 3C 48 and 3C 273. *Astrophys. J.* 140:1-34.

1965

With O. J. Eggen. Luminosities, colors, spectra and motions of white dwarfs. *Astrophys. J.* 141:83-108.

1967

With V. L. Trimble. The Einstein redshift in white dwarfs. *Astrophys. J.* 149:283-298.

1972

Astronomy and Astrophysics for the 1970's. Washington, D.C.: National Academy of Sciences.

1974

With A. I. Sargent. The nature of faint blue stars in the halo. *Astrophys. J.* 28(suppl.):157-209.

1976

Multichannel spectrophotometry and luminosities of white dwarfs. *Astron. J.* 81:323-338.

Degenerate stars with helium atmospheres. *Astrophys. J.* 210:524-532.

1977

With A. Boksenberg, R. Carswell, and K. Shortridge. The rotation and gravitational redshift of white dwarfs. *Astrophys. J.* 212:186-197.

1979

The degenerate stars with hydrogen atmospheres. *Astrophys. J.* 233:239-252.

1984

Spectrophotometry of the white dwarfs. *Astrophys. J.* 276:602-620.