Wallace Leslie William Sargent. 15 February 1935 — 29 October 2012

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WALLACE LESLIE WILLIAM SARGENT
15 February 1935 — 29 October 2012
Wallace Sargent was an astronomer who used large telescopes to great effect. He concentrated on outstanding problems concerning both the origin of the elements and the cosmological evolution of primordial gas clouds. Despite a mainly theoretical education he became an expert spectroscopist and this enabled him to demonstrate that most helium was not formed in stars but was primordial, formed in the Big Bang. This helped to determine the photon:baryon ratio that emerged from it. He played a significant part in the search for the supermassive black holes that were predicted to be in the centres of many galaxies, as is now established. He is most famous for his systematic work with Alec Boksenberg FRS on the intervening hydrogen clouds seen in absorption in the spectra of distant quasars. From their work it appears that most of the 4% of the Universe (by mass) that is now considered to be in normal atoms or ions has indeed been detected, although it is seen at considerable look-back times.

Upbringing and education

Wallace (Wal) Sargent was the elder of two brothers born to Leslie William and Eleanor Sargent (née Denniss) in Elsham, Lincolnshire. His father was gardener to a local estate but the family moved to Winterton during World War II when his father worked for the RAF. After the war Leslie got a job at the steelworks in the nearby town of Scunthorpe. All went well at first but in later years he suffered from poor health and was often off sick. Sometimes the family had to exist on welfare. There were few books in the house but Wal taught himself to read by studying comics. His mother strongly supported his interest in education. He went to the primary school in Winterton from 1940 to 1946, and as an agnostic in later years he was proud to have been given the prize for scripture. He passed the 11-plus exam but chose not to

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go to a grammar school but to go to the local technical school because he thought the more technical training would help him to get a job. Scunthorpe Technical High School was not aimed at academia but normally educated boys up to age 16 years with the aim of giving them sufficient education to be bank clerks or scientific assistants. After Wal reached 16 years of age he at times felt somewhat guilty in having stayed on at school when he could have helped the family monetarily by leaving and taking a job, but by then his reading in encyclopaedias and listening to the fascinating BBC lectures ‘The nature of the Universe’ by Fred (later Sir Fred) Hoyle (FRS 1957) had inspired him to become a scientist. His mother strongly backed his decision to stay on, despite his father’s ill health which led to further economies at home. He shone in all subjects but the school was not used to boys staying on, and the staff struggled to teach at a higher level; he learned most through his reading. By listening to the BBC he developed a love of classical music to which in later years he would listen while observing at the telescope. At school his perseverance was rewarded and he became the first pupil from his school to go to university. He was followed a few years later by his brother, Gordon.

During his first day at Manchester University, Wal met Nick Woolf, who was also reading physics. Nick was a little older because he had already completed his national service, but they struck up a lifelong friendship. On completing their first degrees Wal, Nick and John Hazlehurst all decided to do research in astronomy. Nick opted for observational work and tried to pull Wal in that direction too, but John’s logical and mathematical mind made theory his natural option and Wal was attracted to astrophysical fluid dynamics as James (later Sir James) Lighthill FRS was then one of Manchester’s stars. Franz Kahn (FRS 1993), who gave lucid lectures on both fluid mechanics and plasma physics, became his research supervisor. Wal’s first paper (1)*, co-authored with John Hazlehurst, was published in Astrophysical Journal. It gave a nice treatment of the photons as a collisionless relativistic gas diffusing through a moving stellar atmosphere. Before Wal’s thesis was completed, Kahn took a sabbatical at California Institute of Technology (Caltech) and returned with the knowledge that Jesse Greenstein was looking for bright young postdocs for his project on the abundances of the elements in stars. Wal was keen to expand his horizons and felt quite capable of learning the observational side of the subject, so on Kahn’s recommendation he joined the ‘abundance project’ at Caltech.

**Postdoc at Caltech, 1959–62**

Professor Jesse Greenstein, a renowned stellar spectroscopist, had founded the new Astronomy Department at Caltech, which was the proud owner of the 200-inch Hale telescope, then the world’s largest. The Rockefeller Foundation gave the Hale telescope to Caltech, an institution that Hale had helped to found so that there was a good local university with which his Mount Wilson Observatory could be allied. Greenstein had obtained a large grant to fund postdocs to help him determine the abundances of the elements in stars, a subject made particularly timely by the theoretical work on the origin of the elements in stars by Burbidge, Burbidge, Fowler and Hoyle (Burbidge et al. 1957) (often referred to as B²FH). Greenstein had already recruited Leonard Searle and Ray Weymann from Princeton and Jun Jugaku from Japan, so in the autumn of 1959 they were joined by Wal Sargent, who had a good foundation in theory but almost no knowledge of spectroscopy.

* Numbers in this form refer to the bibliography at the end of the text.
With his good pictorial memory and strong theoretical background, Wal was captivated by spectroscopy; it was a subject well suited to his talents and a tool by which he could investigate anything that shone. In theoretical work his education had not given him the same manipulative ability in mathematics as some of his better-taught, less thoughtful peers, but that was of no consequence for spectroscopy. This would become his chosen tool by which he could explore the Universe. Wal lived in the upper rooms of the Athenaeum, the Caltech faculty club, and in his second year he was joined there by his friend John Hazlehurst, who also became employed on the abundance project but reverted to theory on his return to Manchester a year later. Also housed in the Athenaeum were two astronomical postdocs from Cambridge, Roger Griffin, who worked at Mount Wilson (now Carnegie Observatories), and the author, who did theoretical work in Greenstein’s department and learned much from Maarten Schmidt, the newest faculty member.

We four English postdocs often met in the evenings. On Thursdays after dinner we went to the basement to watch on television the antics of Yogi Bear on the Huckleberry Hound show. Roger later called his house Jellystone in a tribute to Yogi. After the show we often had a foursome at table tennis. Wal, despite the handicap of having only one useful eye, achieved a remarkably high standard, with slams often being slammed back on return. Without transport we were mainly campus-bound except for walks around the neighbourhood, which were then considered somewhat eccentric. It was before the craze for jogging hit the USA. At Thanksgiving Leonard and Eleanor Searle invited Wal and me on a camping trip with Bev and Nancy Oke to Death Valley; this excursion gave us a taste for the wide open spaces of the Southwest. Soon thereafter Roger Griffin acquired a fine old Dodge and organized a great camping trip over the 1960 Christmas break to visit other observatories in the Southwest. Wal got Nick Woolf to come south from Lick Observatory, where he was a postdoc, to join us. We went first to the Steward Observatory, to whose staff Ray Weymann had just been appointed, then saw the Kitt Peak National Observatory in construction, visited both the Lowell Observatory and the US Naval Observatory in Flagstaff, and cooked our Christmas dinner in the bottom of Meteor Crater (figure 1). From there we travelled north and east through a blizzard to Boulder, Colorado. Early next morning we had to take Nick to hospital, where he underwent surgery for a ‘red-hot’ appendix. While Nick was in hospital the rest of us visited the high-altitude solar observatory at Climax. With Nick rapidly recovering in the back of the car, we made our way back to Pasadena via Caltech’s Owens Valley Radio Observatory (OVRO), which had just become operational. That long camping trip in cold weather was made all the more enjoyable by visits to all the national parks and national monuments that lay close to our route. It was the first of what became known as the Athenaeum Enterprises, which took place whenever a public holiday offered a plausible excuse.

When I first met Wal in the autumn of 1960, he was particularly interested in the abundance of dysprosium in stars. I had to admit that I had never even heard of this element, but the reason behind his interest was soon explained. According to theory, 88% of dysprosium is created by the r-process (rapid neutron capture). Furthermore it has lines, or at least one unblended line, in the visible part of the spectrum, so its abundance can be measured. Thus by studying dysprosium one could find out how much r-processing had gone on and discover how much of the abundances of other elements must be attributed to other nuclear processes. Wal was looking beyond his abundance measurements to understand what they might mean, to find out whether they confirmed current theory or would lead
to its modification. A little later, in 1961, Wal and his collaborator Jun Jugaku made a discovery that at first even Jesse Greenstein found hard to believe. They were studying the high-resolution spectrum of the peculiar A star 3 Centauri A (2). The final A indicates that it is the brighter member of a binary system; the first shows it to be a star whose surface temperature is similar to that of Sirius. The star was already classed as peculiar because it had strong lines of phosphorus but weak lines of helium. After a careful wavelength calibration of the spectrogram the other spectral lines gave a consistent velocity, but they found small shifts in the wavelengths of the helium lines inconsistent with the velocity given by the other lines. Rechecking the wavelength calibration with lines close to the helium lines only confirmed that the small shifts were real. An explanation that fitted the pattern of the observed wavelengths was the isotopic shift of the spectral lines due to the helium being predominantly helium 3, the rarer isotope, rather than helium 4. The normal ratio of those isotopes is $1:2500$ but in 3 Centauri A it had to be more than $4:1$—a concentration factor of more than $10^4$. This was the first time that an isotopic shift of helium had been observed in any star, but the peculiar A stars are renowned for their strange abundances, with europium sometimes enhanced by even greater factors. Such a weird result therefore had to be considered possible, and indeed later work has given a likely explanation of it (see below). It was only great attention to detail that allowed them to detect the small shifts and to prove that they were real (3).

The last of the Athenaeum Enterprises took place in April 1961. At that time the Glen Canyon dam had not been built, so the Colorado river flowed freely through the area now covered by Lake Powell. It took a rugged 16-mile hike to reach what was then the least visited national monument in the USA: Rainbow Bridge, deep in the Navaho Indian Reserve. Roger decided we should hike in on one day and hike out on the next. It was quite hot but the steep red-rock canyons made stunning scenery. One of us took a wrong turn, but after a desperate search he was found just as light began to fail, so we ate in near-darkness beside the wonderful...
Wallace Leslie William Sargent

natural bridge. Next day started well enough but the 2000-foot rise up Cliff Canyon in the heat of the day sapped our energy. In the end only Roger made it back to the car by nightfall. The other four of us attempted to sleep by the trail without food or water, got up at first light and found Roger lying in his sleeping bag next to his car.

In autumn 1961 the Astronomer Royal, Richard (later Sir Richard) Woolley FRS, came to make observations with the Mount Wilson telescopes. On hearing that Wal Sargent would soon be available, he at once offered him a job at the Royal Greenwich Observatory with the added inducement that he would have access to the 74-inch telescope in Pretoria, then the largest southern telescope. This gave Wal a spell back in England.


Wal took up his post as Senior Research Fellow in the autumn of 1962. He joined the Astrophysics Department under Bernard Pagel (FRS 1992), which was concerned with determining the abundances of the elements in stars, a subject he already knew well. Pagel was more concerned with the theory underlying the determinations and with comparing astronomical abundances with those determined on Earth and in the Solar System. Wal wanted new spectra to discover what was in other stars and to understand the peculiarities that led to their abundances. Pagel was a good critic and was often content to use the spectra that others had taken to obtain abundances of higher accuracy from them. The winter of 1962 was a cold one, and soon thereafter Pagel went on sabbatical to Mount Stromlo in Australia. Wal was now needed at Herstmonceux to keep the Astrophysics Department alive while Pagel was away. The chance of working on the 74-inch telescope in Pretoria receded into the future.

In the summer of 1963 Margaret Evans (now Penston) and Anneila Isobel Cassels, two new Edinburgh graduates in astronomy, arrived to take up jobs as assistants to Woolley. This provided a ray of sunshine, and in 1964 Wal and Anneila were married in Scotland.

Despite the joy of finding a wife, Wal was not happy at Herstmonceux. He felt deprived of the ability to explore the Universe by spectroscopy. He needed a big telescope in a good climate. Here he had neither, and with Pagel away he had no other spectroscopist to talk to. He met Geof. Burbidge (FRS 1968) at a conference and told of his dismay. Burbidge was building up the new department at University of California at San Diego, and as part of that university they had access to the new 120-inch telescope at Lick Observatory. He offered Wal an assistant professorship in physics and gave him the opportunity to visit Mount Stromlo, where his former collaborator Leonard Searle then was. They resumed writing papers together on the magnetic peculiar A stars. In San Diego Peter Goldreich (ForMemRS 2004) was on the staff, and soon he and Wal were asking John Bahcall to join them there. The three of them had agreed that they should all try to get to the same place because their different talents would complement each other. John Bahcall’s reply from Caltech was blunt: this place is better than UC San Diego. In 1966, after less than two years, Wal got a letter asking him to accept an assistant professorship at Caltech. He would have access to both the 100-inch telescope on Mount Wilson and the 200-inch at Palomar. The choice was obvious. He showed the letter to Burbidge, who at once advised him to take it. Goldreich moved to Caltech at the same time, to the Department of Earth and Planetary Science. Both he and Wal would remain there until
Biographical Memoirs

retirement, but that was not true of John Bahcall, who in 1969 was asked to head Astrophysics at the Institute for Advanced Study in Princeton, a position he held with great success and distinction.

THE PECULIAR A STARS

Starting from his collaboration with Jun Jugaku and continuing with Leonard Searle (4), Wal studied all aspects of the peculiar A star phenomenon. Normal A stars rotate quite rapidly and several show enhanced metal lines, but the peculiar stars all rotate slowly and commonly have magnetic fields of more than 1000 gauss (1 G = 10^{-4} T). Roughly half of them show spectrum variations as they rotate. Regions of different magnetic field show different anomalous abundances. Sargent and Searle showed that there was a sharp division between those stars showing strong manganese lines and those showing an anomalous silicon:oxygen ratio. This division was not just a function of surface temperature; it also depended on surface gravity. Jugaku and Sargent (10) showed that the peculiarities were a surface phenomenon, with the deeper layers of the atmospheres, where the continuum and the wings of the Balmer lines were formed, being just like those in normal stars. Thus the phenomena were crucially dependent on atmospheric properties. The idea that the strong magnetic fields might produce fast particles and surface nuclear reactions did not fit comfortably with this sharp dependence on precise atmospheric parameters.

George Michaud was a nuclear-physics student at Caltech partly supervised by Wal, who convinced him of the crucial role of the atmospheres in the peculiar A stars. Michaud saw that this did not fit any explanation via nuclear reactions, and looked for another mechanism by which different elements and isotopes might be segregated. An atom or ion can achieve some of its support against gravity by absorbing an outward-moving photon but re-radiating in all directions. Such effects could produce a slow diffusion outwards of elements that absorb photons easily but are not too massive. However, diffusion is very slow and is easily overcome by any turbulent convection or circulation currents in the atmosphere. Instead of first embarking on detailed calculations of which ions could levitate on the blast of radiation coming from below, Michaud stepped back from the detail to look at the global picture. If such effects were of importance to any stars, where in the colour–luminosity diagram would those stars lie? The stars must have a strong flux of radiation compared with their gravity. They must have radiative non-convective atmospheres and they must be devoid of the Eddington–Sweet circulation currents that are prevalent in rapidly rotating stars. A strong magnetic field will be frozen into the ionized fluid and will further inhibit atmospheric turbulence. With those criteria he showed that the A stars are the zone of the colour–luminosity diagram that is most likely to show diffusive effects. Only then did he determine what would sink or float under the combined action of the blast of radiation, gravity and pressure. $^3$He has almost the same spectrum as $^4$He, so they receive the same radiative support. However, $^4$He is heavier, so it sinks, leaving a concentration of the lighter isotope in the outer atmosphere and an overall underabundance of helium there. Michaud gave a fulsome acknowledgement of Wal Sargent’s advice at the end of his paper (Michaud 1970).
Most of the energy that can be extracted by nuclear fusion comes out at the first step, the fusion of hydrogen to make helium, so any discussion of the energy budget of the Universe must answer the question ‘When was the helium formed?’ Some is certainly being formed in stars, but is that the main source? The stars of the globular clusters and the associated high-velocity stars, which are probably the oldest stars in the Galaxy, are very weak in metals, with metal abundances of the order of 1% of those in the Sun. Is the helium abundance in such stars similarly only 1% of its solar abundance (28% by mass)? This was the next problem that Sargent and Searle set out to solve. In those days the stars in globular clusters were too faint for high-resolution spectroscopy, and only in very hot stars are the strong lines of helium present. In globular clusters the brightest stars are red. However, many of the very metal-poor globular clusters have some stars that populate a horizontal branch in their colour–luminosity diagrams that stretches out to the blue, crossing the colour range of the A stars at higher luminosities and lower masses and proceeding even further bluewards. The globular clusters are distant and these are by no means their brightest stars, so they were too faint for detailed spectroscopy; however, even at low resolution the strong helium lines should be visible in their spectra unless the helium abundance was low. Sargent and Searle (5, 6) showed that the expected helium lines were absent or very weak. In three globular clusters they estimated that the abundance of helium was lower by a factor of 100, a result in agreement with the metal abundances. They backed this up by taking spectra of some blue population II high-velocity stars that were listed by J. Feige. If this were true, all the helium must have been formed after the globular clusters. The formation of the Galaxy must have been accompanied by fantastic fireworks. Might this be related to the recently discovered quasars? However, these helium results came with a caveat. The stars were so faint that little was known about their spectra. Could it be that their atmospheres suffered from the same disease that gave the low helium abundance in 3 Centauri A and other peculiar A stars? This was 1968, before Michaud’s work. A year later the weight of the evidence shifted dramatically. They got a fine spectrum of Feige 86, a high-velocity star that showed very weak helium lines, but this higher-resolution spectrum showed the same strong phosphorus line seen in 3 Centauri A. This star, and probably the others too, were indeed suffering from the same phenomena that caused the abundance anomalies of the peculiar A stars. Sargent and Searle at once withdrew their claim that such stars were truly helium-poor (7).

Evidence from stellar-structure calculations was now suggesting that there must be a significant helium abundance in these stars. Eddington’s theory of the mechanism causing some stars to pulsate rested on the behaviour of partly ionized hydrogen, but he could not get it to work quantitatively. However, now that helium was known to have a large abundance in the Sun, others had looked for the excitation of pulsation in the helium ionization zone, and this made the theory work. The RR Lyrae pulsating stars occur abundantly in metal-poor globular clusters, so if this theory was correct these stars must contain at least 20% of helium by mass, far more than in the face-value results from spectroscopy.

Wal Sargent’s wide interests allowed him and Searle to solve the helium problem, but the solution came unexpectedly, from research that was initially unrelated. Wal was an admirer and friend of the brilliantly original but erratic and occasionally irascible Fritz Zwicky. Zwicky advocated the study of outliers, the objects of any class that were in some way abnormal, because they often showed in extreme form characteristics that were important for...
understanding the normal objects. Zwicky retired in 1968 and Wal inherited several of his observational programmes, the studies of compact and of dwarf galaxies (15) and the running of the Palomar supernova search. Wal conducted a spectroscopic survey of the dwarf galaxies on Zwicky’s lists. Among these were two objects of low metal abundance that contained young stars sufficiently blue to ionize the surrounding gas. Those galaxies were much too far away for the stars in them to be examined spectroscopically, but the emission lines in the hot gas could be analysed for helium as well as metals. Searle and Sargent soon saw that, unlike the metals, helium was of normal abundance (14). The floor to helium abundances was found in all metal-poor galaxies and gas clouds. It remains important for the determination of the photon: baryon ratio in the Big Bang. Daniel Kunth and Wal Sargent later made a detailed study that established 24.5 ± 0.03% as the primordial abundance of helium by mass (20).

### The Palomar supernova search and Sky Survey II

Ever since his 1934 paper with Baade predicting that neutron stars would be formed in supernova explosions (Baade & Zwicky 1934), Zwicky had been interested in supernovae, so in 1968 Wal inherited an ongoing programme to discover new supernovae with the Palomar Schmidt telescopes. Charles Kowal was one of those involved in this survey (13), and he would at once alert Wal to any new supernova found. Wal would ensure that spectra were taken as soon as possible after the discovery (21). This was before the study of supernovae became a refined art, as ways were found to get accurate distances to supernovae of type 1A. In the 1980s Neugebauer and Sargent obtained a grant to repeat the Palomar Observatory Sky Survey (POSS) (25). Both the telescope and the photographic plates would be significantly improved. Although the Schmidt corrector plates have little power, the glass refracts different colours by different amounts so the images are slightly blurred by chromatic aberration. The problem is even worse if the same corrector is used for both red and blue survey plates as was done in the original Palomar survey. David Brown of Grubb Parsons was glad to have the challenging job of making an achromatic corrector plate for the 48-inch Schmidt as his last before retirement. Indeed, it was the last contract before Grubb Parsons of Newcastle went out of business. Eastman Kodak gave the improved IIIaJ and IIIaF photographic plates with their last big donation before they, too, went out of business under the influence of the new charge-coupled device (CCD) detectors. POSS II was completed in 1999, the last of the great photographic sky surveys, with 897 plates in each of two colours. Although Wal was involved in the funding and oversight of this great undertaking he was not involved in the night-to-night direction nor in the taking of plates. With the end of the millennium, digital methods replaced analogue chemical ones.

### Black holes in the nuclei of galaxies

Wal was appointed to Caltech as a spectroscopist who could make good use of the telescopes when the brightness of the Moon made work on faint objects impossible. However, his interests soon veered to the extragalactic world, so he started to apply also for the more sought-after telescope time in the dark of the Moon. The wish to explore Zwicky’s dwarf galaxies certainly pulled him in this direction, but so did the influence of radio astronomy. The
group under Sir Martin Ryle FRS at Cambridge had published the third Cambridge catalogue of radio sources (3C), and with positional refinements from Caltech’s OVRO several of them had been shown to be quasars at large redshifts. When Maarten Schmidt (1963) first demonstrated that 3C 273 had a large redshift, despite its optical brightness, quasars were thought to be a totally new class of objects. Then Ryle showed that in the radio spectrum they were indistinguishable from radio galaxies; Wal and other optical observers found that their spectra had much in common with the spectra first seen by Vesto Slipher (Slipher 1917), when he explored the galaxies remarked upon by William Herschel as having bright nuclei. Several such objects were collected and compared by Carl Seyfert in 1943, so this class of galaxy still bears his name. Seyfert galaxies have strong broad lines in emission that can be found without tiresomely long exposures. Like quasars they also vary optically, and Ray Weymann showed variations over a period of months in the broad wings of the emission lines. Wal cooperated with Bev Oke and with Schmidt over the interpretation of the spectra of two radio galaxies (9), but he then turned his attention to the spectra of the much commoner Seyfert galaxies (11, 27), which are usually spiral galaxies with bright nuclei. Their spectral similarity to quasars led him to believe that quasars might be exceptionally active Seyfert galaxies. In 1969 I revisited Caltech shortly after proposing that the nuclei of all substantial galaxies were stars gathered around giant black holes (Lynden-Bell 1969), which were collapsed old quasars. In January 1970, Ron Ekers and I, using the OVRO radio telescopes, found small-scale structure but failed to find definitive evidence of a black hole in the Galactic Centre. Later that year, Wal and I were both invited to the Vatican for a conference on the nuclei of galaxies. Figure 2 shows Wal with Fred Hoyle on their way to one of the sessions. It was not until many years later that beautiful work by Genzel et al. (2003) and independently by Ghez et al. (2005) in the infrared established the presence of a black hole of $4 \times 10^6$ solar masses in the Galactic Centre. In 1978 Wal, working with five others (17), looked for the supermassive black hole that was predicted to be in Messier 87, the central galaxy in the Virgo Cluster, which has a jet spurting from its nucleus. They found a central mass concentration of $5 \times 10^9$ solar masses, but although this mass lay within a radius of 1.5 seconds of arc (110 parsecs) of the centre, they could not definitively deduce that it must be a black hole. However, the spectrum of the stars in that region was the same as that from the stars farther out, yet the mass:light ratio of the central region was 10 times that of the stars elsewhere. Thus there was good circumstantial evidence for the supermassive black hole predicted. In the following year, he with others (18) produced evidence for a supermassive object of $2 \times 10^9$ million solar masses in the nucleus of NGC 6251, an elliptical galaxy whose spectacularly extended radio emission was found by the 6C survey under John Baldwin FRS. Despite this work Wal was still in doubt as to whether the elliptical galaxies had giant black holes. In 1987 he wrote a paper entitled ‘The evidence for and against the existence of supermassive black holes in E galaxies’ (23). The first really definitive result came in December 1994 from Very Long Baseline Interferometry (Miyoshi et al. 1995) on the nucleus of the spiral galaxy NGC 4258, which gave a black-hole mass of $4 \times 10^7$ solar masses. This was followed by the work on our Galaxy’s nucleus alluded to above. From 1999 onwards Wal with others wrote about 15 papers concerned with determining the masses of the central black holes in several galaxies, to tie down the relationship between the mass of the central bulge and that of the nuclear black hole (28–30).
Before he left Caltech for Princeton, John Bahcall had been working on the absorption lines seen in quasar spectra. There were single Ly $\alpha$ lines of hydrogen but also strong damped Ly $\alpha$ lines associated with metal lines of the same redshift. There could be more than one of these absorption-line systems with different redshifts in the spectrum of a single quasar. Most of them had significantly smaller redshifts than the quasar itself and there was controversy as to whether the corresponding gas clouds were pushed out at considerable speed by radiation pressure or whether they were clouds that happened to be encountered by the light on the way to us. With photographic spectra it was difficult to obtain good quantitative data on the widths and strengths of these absorption lines.

Alec Boksenberg FRS had developed a new photon-counting detector that was not only much more sensitive than photographic plates, it was also photometrically accurate. Wal as a staff member had lots of observing time and good astronomical programmes, so Boksenberg suggested that they collaborate. After their first observing session Wal saw the great advantages of this instrument, and the collaboration continued even after the eventual replacement of the instrument by CCDs. The main, but by no means the only, programme they pursued was the deep cosmological study of the intervening clouds in the spectra of high-redshift quasars. So
successful was this work that many consider it Wal’s main contribution to astronomy. Wal saw that a systematic survey of these absorptions as a function of redshift could be made with this detector. With major results published from 1978 (16, 19) Wal and Boksenberg made the study of the intergalactic medium a major subject in astronomy. The clouds giving only Ly $\alpha$ absorptions were ubiquitous and uniformly distributed except that their numbers increased at high redshift where it became increasingly difficult for photons to traverse the mass of lines forming the Ly $\alpha$ forest. Indeed, more of the atoms in the Universe were detected in these clouds than can now be seen in galaxies and the gas around them. This difference, which may be as great as fourfold, is not considered a real problem (31). It merely reflects the fact that at redshifts greater than two, more of the atoms were in a readily detectable form. Correlations in cloud numbers along the line of sight were studied from the statistics of the redshifts. By looking at differences between sight lines to close optical pairs of quasars they also studied correlations transverse to the line of sight. By looking at sight lines to a lensed quasar they could put limits on the sizes of individual absorbing clouds. A second study of the clouds giving metallic absorption lines showed that they occurred only when the line of sight passed within about three Holmberg radii of a galaxy with almost the same redshift (24, 26, 32). They also showed the gradual enrichment of the circumgalactic clouds as redshifts diminished. The broad damped Ly $\alpha$ systems were sometimes associated with distant galaxies at the same redshift but near the sight line to the quasar. By looking at sight-lines that passed close to another quasar it was possible to detect the extent of the ionization caused by the second quasar. All this illustrates the power of absorption-line spectroscopy when a bright background source shines right through the object under study. When the hydrogen causes sufficient shielding, so that most atoms are in the ground state, the strengths of the various absorption lines give the relative abundances of the elements seen. As a result the spectrograph becomes a very sensitive tool. Studies of the intervening clouds continued as a key project on the Hubble space telescope with a much larger team. However, although Wal played his part in this large collaboration, it gave him far less pleasure than designing the observing programme with one or two others and reducing the data with his students. Although the Hubble telescope can see better in the ultraviolet and has higher resolution than ground-based telescopes, it has only one-sixteenth of the light grasp of the Keck telescope, so for most spectroscopic observations the ground-based large telescopes are better. To work in the Southern Hemisphere with the Carnegie Las Campanas Observatory’s Magellan telescopes, Wal teamed up with Michael Rauch of Carnegie, who became a soulmate as well as a colleague. They wrote many papers together.

**Telescopes and planning**

When Wal came to Caltech he had access to the world’s largest telescope, the Palomar 200-inch, and also to the fine spectrograph on the Hooker 100-inch telescope on Mount Wilson, which he used for his work on the peculiar A stars. Then Caltech joined with the University of California to build the twin 10-metre Keck telescopes on Hawaii. Wal was co-chair of the Keck Science steering committee that oversaw the design and construction of the Keck Observatory in 1984–93 and its initial suite of instruments. Their good planning led to the immediate success of those telescopes, and in his later years much of Wal’s work was done with them. Meanwhile Carnegie had closed down its operations on Mount Wilson and with the foresight
of Horace Babcock had built the 100-inch and then the twin 6.5-metre Magellan telescopes at the excellent site at Las Campanas in Chile. Through his friend and collaborator Michael Rauch, Wal had access to the Magellan telescopes for work in the Southern Hemisphere. He particularly enjoyed his visits to Las Campanas. Quite apart from the engineering, all telescopes need detailed planning to decide priorities of the subsidiary instruments used to analyse the light. Older telescopes were designed to analyse one object at a time, but more recently systems have been devised to take spectra of hundreds or even thousands of objects in the field simultaneously. There is tension between getting the greatest spectral coverage for the intense study of a single object and getting a wider field of view so that many objects can be observed simultaneously. On the committees concerned with such matters, Wal particularly enjoyed the greater contact with the astronomers from Lick and others from the University of California. Although he played an active part in deciding which instruments should be built to what specification, he was not himself an instrument designer; rather he was an enthusiastic user of the final products.

LIFELINE AND HONOURS

Wal and Anneila wrote only two astronomical papers together (8, 12), both on the spectroscopy of peculiar A stars, in the period 1967–69, before their daughters, Lindsay and Alison, were born. Bringing them up somewhat delayed Anneila’s return to astronomical work, and when she did so she worked well away from Wal’s shadow. She became Peter Goldreich’s graduate student working with radio and then millimetre telescopes on the birth of stars. Later she became a full professor in Caltech and director of OVRO. In 2000–02 she was President of the American Astronomical Society. Bravely she took on the difficult job of Vice-President of Caltech for Student Affairs. More recently she succeeded Wal in the Ira S. Bowen Professorship of Astronomy. Wal was an avid Manchester United fan, but in the USA he learned to enjoy baseball and backed the Los Angeles Dodgers. He was a good critic of the play and this gave him a natural rapport with his son-in-law, Dan Hubbs, who is now the head baseball coach of the University of Southern California. In later years his Japanese friends introduced him to sumo wrestling and he soon learned to enjoy watching it on TV. On a visit to Japan, at his request, he got to see some of the great sumo stars in a practice session. When the children were young they would come from school to either Wal or Anneila at work to be taken home. They remarked that Anneila was always busy when they arrived at her office. Either she would be on the phone exercising her organizational skills or she would be at the computer terminal. Not so with Wal: more often he would be gazing out of the window, deep in thought. In this sense Wal was still a theorist, although he loved observing and particularly spectroscopy. It was this combination of thought and observation that led to his success. Starting when the children were small and continuing when they were teenagers, the family came to Britain every summer to keep up with the grandparents. Here they met their cousins, Gordon Sargent’s family, also flying in from the USA. Remembering his mother’s influence, Wal took an active interest in Lindsay’s and Alison’s education. In later years when they got married (figure 3) and had children, he much enjoyed being a grandfather. Wal was a very loyal and good friend but liked the role of outsider. He enjoyed a good-natured grumble against those in authority. His heroes were the revolutionary Fritz Zwicky, and also Fred Hoyle, whose roots were close to his own. Nevertheless when the time came he shouldered the responsibilities of head of department for eight years and director
of Palomar for three. He was an exceptional supervisor of graduate students, both leading them into new fields and inspiring them, while giving them ample opportunity to think for themselves. The fine later careers of his students, Don Cox, Pat Osmer, Clark Christensen, George Michaud, John Huchra, Bob O’Connell, Bill Bagnuolo, Ed Turner, Peter Young, Steve Kent, Matt Malkan, Daniel Kunth, Alex Fillipenko, Chuck Steidel, Todd Small, Rob Simco and George Becker, are a tribute to his tutelage. He kept up with many of them after they left Caltech and rejoiced in their success. In his lectures he conveyed to his class not only the subject matter but also his attitudes, and many now remember him through his way of thinking rather than the astronomical facts he discussed.

In April 2011 Wal and Nick Woolf were again at Rainbow Bridge, meeting Roger Griffin and me, who repeated the hike on the 50th anniversary of the original expedition. The reunion was the basis of the film *Star Men* by Alison Rose, who knew both Nick and me from her earlier work. Eighteen months later, Wal’s blood count fell to an unsustainable level and he died in hospital from an acquired infection.

Wal is survived by his wife, Professor Anneila Sargent, and their two children, Lindsay Eleanor (Berg) and Alison Clare (Hubbs), together with four grandsons, and by his brother, Gordon, who followed him to the USA and retired as vice-president for research and dean of engineering at the University of Dayton, Ohio.

**Caltech career**


Director, Palomar Observatory, 1997–2000

Ira S. Bowen Professor of Astronomy, 1981–2012
Honours and awards

1968–70 Alfred P. Sloan Foundation Fellow
1977 Fellow of the American Academy of Arts and Sciences
1981 Fellow of the Royal Society
1987 George Darwin Lecturer, Royal Astronomical Society (22)
1991 Dannie Heineman Prize, AAS and American Institute of Physics
1994 Catherine Wolfe Bruce Gold Medal, Astronomical Society of the Pacific
1998 Associate of the Royal Astronomical Society
2001 Henry Norris Russell Lecturer, American Astronomical Society
2004–07 Vice-President, American Astronomical Society
2005 Member of the US National Academy of Sciences

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The frontispiece photograph is reproduced by courtesy of Anneila Sargent. (Online version in colour.)

REFERENCES TO OTHER AUTHORS


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