RETROSPECTIVE

Alexander Dalgarno: From atomic and molecular physics to astronomy and aeronomy

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As Sir David Bates wrote in 1988, "There is no greater figure than Alex Dalgarno in the history of atomic-molecular-optical [AMO] physics, and its applications" (1). Prof. Alexander Dalgarno (Harvard) passed away peacefully on April 9, 2015 at age 87 in the presence of his long-term companion, Fern Creelan.

During a career spanning 60 years, Alex produced about 750 publications covering a vast array of topics spanning all of modern AMO physics. His scientific accomplishments are so broad that even many people who knew him were only aware of a small portion of them. Alex's development and implementation of new theoretical quantal methods, and his application of these to observations and experiments, led to about 200 publications in astrophysics and 100 in atmospheric science. Alex's impact derived from the combination of his seminal insight and unparalleled, boundless, and sustained productivity. His long career is described in his autobiographical article "A serendipitous journey" (2) and in the books written in his honor (1, 3–5).

Alex, a twin and the youngest of five children, was born in London in 1928 and grew up during the Second World War. Despite the distraction of air raids, he did well in grammar school and enjoyed mathematics. Alex also excelled at sports, especially soccer, and was invited to try out for the Tottenham Hotspurs club.

In 1945 Alex started to study mathematics at University College London. After his degree in 1947, he was uncertain about what to do next. By chance, in the corridor of the physics department, he encountered Sir Harrie Massey, who offered Alex a fellowship toward a doctorate in atomic physics. Alex accepted and made the switch to physics. This episode highlights the importance of spotting talent at an early age. Alex himself excelled at nurturing early career researchers, and the "Dalgarno scientific family tree" contains 70 graduate students and 36 postdocs. Alex guided and mentored all of them with the utmost thoughtfulness and care.

After completing his doctorate in 1951, Alex was offered a Lecturer position in Applied Mathematics at the Queen's University of Belfast. Together with David Bates, he built a world-leading department in atomic and molecular physics over the next 15 years. Landmark advances were made on a large number of topics (5), including long-range interactions, ionization, polarizability, electron capture, and charge exchange reactions, to name just a few. The results and methods provided a solid basis for the many applications later in his career. Indeed, in Alex's view, "astrophysics could be seen as almost entirely applied AMO physics" (2).

Although science occupied much of his life, Alex had broad interests in literature and continued to be active in sports, playing tennis and squash into his 80s. In 1957, Alex married Barbara Kane, with the poet Philip Larkin as the best man at his wedding. Alex and Barbara had four children but separated after 10 years.

During Alex's time in Belfast, David Bates persuaded him to apply his calculations on electron capture to aeronomy. Their conclusion that previously inferred altitudes of the night- and day-glow sources were several hundred kilometers too high was subsequently confirmed by instruments carried by V2 rockets (the same rockets he had seen in wartime London). Alex derived much joy from combining models with observations and experiments. His realization that microscopic atomic processes are critical in governing the macroscopic response of the upper

Alexander Dalgarno and Ewine van Dishoeck pose by the statue of Albert Einstein outside the National Academy of Sciences headquarters in 2002. Image courtesy of Ewine F. van Dishoeck.

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atmosphere to the action of the Sun whetted his appetite for other applications. It proved to be a turning point for his future research directions and his move to the Harvard-Smithsonian Center for Astrophysics (CfA) in 1967.

At the CfA, Alex vigorously pursued AMO physics, theoretical chemistry, aeronomy, and astrophysics in a stimulating environment inhabited mostly by astronomers. One of his first ventures into astronomy concerned H_2, the most abundant molecule in the universe, at a time when astronomers were still focused on atoms. Alex computed dissociation probabilities and photodestruction rates for H_2 in any specified radiation field. The resulting continuum spectrum matched very well that measured by Gerhard Herzberg a few years earlier in the laboratory, but which was not understood at the time (6).

Over the next 40 years, Alex and his collaborators opened up and solidified molecular astrophysics, also known as astrochemistry, across all fields of astronomy. His many seminal contributions ranged from cosmology to interstellar clouds, supernova remnants, shocks, comets, and planetary atmospheres. In 1984, Alex founded the working group on Astrochemistry of the International Astronomical Union, whose main activities are to coordinate conferences worldwide, and he succeeded in highlighting astrochemistry as a uniquely significant component of astronomy.

In the early 1980s, Alex became increasingly concerned about the future of AMO physics in the United States, where it threatened to vanish from physics departments. Alex led a National Science Foundation proposal that resulted in the founding of the Institute of Theoretical Atomic and Molecular Physics (ITAMP) at the CfA in 1988. ITAMP provides a fertile breeding ground for young AMO physicists through a vigorous postdoctoral and visitor program, and ITAMP fellows have been successful in obtaining academic positions across the United States, thus securing the future of the field.

Alex characterized his own research as follows: "It is often said, by theorists, that physics is embodied in its equations, but I think it is to be found in the solutions to the equations. I have spent much time seeking those solutions" (2). In a fitting culmination to his work, Alex spent the last decade and a half of his career, when in his 70s and 80s, opening up the theory of ultracold atoms and molecules (5).

Alex was remarkably efficient: his research never seemed to suffer from his considerable administrative load. In between duties, teaching, scientific discussions, playing sports, and hosting dinners, Alex managed to produce near-final handwritten paper drafts by early the next morning. He served as the editor of the *Astrophysical Journal Letters* for nearly 30 years, starting in 1973, and served as the Chair of the Harvard Department of Astronomy from 1971 to 1976, and the Acting Director of the Harvard College Observatory and then Acting Director of the CfA from 1971 to 1973.

Alex's phenomenal cognitive abilities, his clarity, his love of science and constant drive for excellence and integrity, his polymathic store of knowledge, and his search for "those solutions," inspired his many students and collaborators. Alex treated everyone with fairness, respect, generosity, and encouragement. He was "a master juggler feeding out ideas and taking any ideas back, no matter how badly thrown, fixing them back into the pattern and throwing them back with spot-on timing and precision" (5). At conferences, Alex usually spent more time talking with junior students and with researchers from developing countries than with his well-established colleagues. He was not a man of many words: he would settle lengthy debates between others by simply going to the blackboard and writing down a few key equations and numbers.

Philip Larkin wrote: "I feel the only thing you can do about life is to preserve it, by art if you're an artist, by children if you're not" (7). At his 80th birthday celebration, Alex cited his former students and postdocs to be his real legacy, rather than his research achievements. We are fortunate and proud to be among his scientific children.

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4 Hartquist TW, Williams DA, eds (1998) *The Molecular Astrophysics of Stars and Galaxies* (Oxford Univ Press, Oxford).

5 Babb JF, Kirby K, Sadeghpour H, eds (2010) *Proceedings of the Dalgarno Celebratory Symposium* (Imperial College Press, London).

6 Dalgarno A, Herzberg G, Stephens TL (1970) A new continuous emission spectrum of the hydrogen molecule. *Astrophys J* 162:L49–L53.

7 Larkin P (2010) *Letters to Monica*, ed Thwaite A (Faber and Faber, London).