THE KAVLI PRIZE

An Autobiography by:
Ewine Fleur van Dishoeck
Kavli Prize Laureate in Astrophysics 2018

I was born in 1955 in Leiden, the Netherlands, the city in which I would spend most of my life. My father was a medical doctor and in his later years professor of ear, nose, throat at Leiden University. He met my mother, who was an elementary school teacher and considerably younger, during the second world war when she provided a hiding place during the German occupation. My parents clearly had an academic career for me in mind: my birth announcement shows a baby wearing a stethoscope crawling toward the university with the motto 'vires acquirit eundo' ('she will gather strength along the way'; from Virgilius' Aeneid). This turned out to be a very appropriate quote. My parents got only one aspect wrong: I never had any inclination to study medicine.

My childhood was a happy and carefree period; my mother's teaching philosophy was that play was more important than study for young children. I was enrolled in a Montessori elementary school, which encourages self-study and collaborative play. I also started to play the violin during this time. Among my schoolfriends was Jette van de Hulst, daughter of the famous astronomer Hendrik van de Hulst (who predicted the 21 cm radiation of hydrogen). Birthday parties took place in the domes at the Sterrewacht in the center of Leiden, where van de Hulst and Oort lived. It was my first encounter with astronomy, but little did I know then that the Sterrewacht would become so important in my later life. For high school, I went to the Stedelijk Gymnasium ('Grammar School'), well known for its high academic level. For the first few years, lectures consisted mostly of Latin and Greek, together with modern languages and mathematics. I still enjoy the benefits from studying the classics in depth, since it teaches one to concentrate and properly dissect any piece of text.

My first encounter with science came in spring 1969, after my father had retired from Leiden University and the family went on a six month work visit to San Diego. I was enrolled in the public Horace Mann junior high school and chose subjects that I did not (yet) have in Leiden, most notably science, which was taught by an inspiring female African-American teacher (only in hindsight did I realize how special that must have been at that time). We enjoyed the sunny life in California, the era of the pop music, often visited the San Diego Zoo, and travelled to the Grand Canyon. Summer was spent in Mexico where we saw the Moon landing from a hotel room.

Shortly after we returned to Leiden my father passed away suddenly, on the eve of my 15'th birthday. By the end of high school I had become fascinated with chemistry at the molecular level thanks to a very good teacher, Gerard Desar. I therefore started studying chemistry at Leiden University in 1973, but quickly discovered that I liked physics just as much. After my bachelor degree in chemical physics, I felt that I would benefit from more mathematics and got my bachelor degree in mathematics a year later.

My first years at the University were clearly filled to the rim with course and practical work, but I continued to enjoy music. Since 1971 I played in the Leiden Youth Orchestra and in the gypsy music orchestra Csárdás, playing Hungarian and Romanian folk music. We had many 'gigs' at parties and other festivities. It is there that I met my future husband, Tim de Zeeuw, with both of us playing the violin. Tim studied astronomy and mathematics in Leiden so we also had a number of courses in common. We enjoyed long vacations together as students, one trip to Greece to visit all the historic sites that we had studied in high school, and one six-week trip to the western US which included a brief visit to Caltech. Our love for the spectacular mountains and forests in that area was born during that trip, and over the next 40 years we have continued to go camping and hiking every summer somewhere in the western US.

One of the research projects for my MSc degree was in theoretical quantum chemistry on the photodissociation pathways of the CH4+ ion under the guidance of Marc van Hemert. He inducted me into the field, always ensured that state-of-the-art quantum chemistry software was running on the then biggest computer (an IBM mainframe, still using punch cards), and would become one of my long term collaborators. Photodissociation has continued to be one of the main themes throughout my career with a major review in 2017.

Quantum chemistry suited me well, so I was convinced by 1979 that I wanted to continue in that direction for my PhD research. Unfortunately, the professor of theoretical chemistry at Leiden had just died and it became clear that there was not going to be a successor. So they advised me to look elsewhere. By chance, Tim had just taken the Interstellar Medium course from Harm Habing, which included a lecture on interstellar molecules. 'Isn't that something for you?' he asked. Habing brought me in contact with his colleague, Teije de Jong, who recommended that I go to Harvard to the group of Alexander Dalgarno, world-leading in the new field of astrochemistry. In summer 1979, Tim and I were camping in Canada in the Mt Tremblant National Park, where the first symposium of the International Astronomical Union (IAU) on Interstellar Molecules took place. There I met Dalgarno who kindly invited me to spend some months at Harvard to get a start and work on photodissociation processes of astrophysically relevant molecules, most notably OH. Dalgarno would become my PhD supervisor and lifelong mentor: he set the tone with his phenomenal knowledge, his clarity, his love of science and constant drive for excellence and integrity, and his agility in moving easily between molecular physics and astronomy. He treated everyone with fairness, respect, generosity and encouragement (both in science and sports!).

In the meantime, Habing was able to convince the Netherlands Foundation for Scientific Research, NWO, to provide me with a grant to continue my PhD in Leiden, with regular visits to Harvard. There I also met John Black, then a postdoc, who patiently introduced me to the physics and chemistry of interstellar clouds. In June 1982 I went to Chile to do observations of interstellar C2 to test the models that John and I had developed: a fantastic experience that transformed me from a pure quantum chemist to an astronomer. Tim joined at the end of the run and we subsequently traveled for three weeks through Bolivia and Peru. This included taking the famous narrow gauge train from Calama in Chile to La Paz in Bolivia; we crossed the high-altitude plain at 5000m not too far from where three decades later the Atacama Large Millimeter/submillimeter Array (ALMA) would be inaugurated.

1982 was also the year in which I first participated in a conference on a far-infrared-submillimeter telescope in space, then called FIRST, organized by Thijs de Graauw from the Netherlands Institute for Space Research, SRON. This mission, which ultimately became the Herschel Space Observatory, would be important throughout my career as further described below, but I did not realize then that the first data would only appear in 2009! It illustrates the very long timescales of astronomical facilities, from conception to actual operation, of typically 25-30 years. It alerted me early on to the need for long term planning, looking decades ahead and making sure science stays in step with instrumentation along the way.

On June 19 1984 Tim and I graduated on the same day cum laude at Leiden University. On July 26 we were married and in late August we moved to the US for our postdoctoral fellowships at Harvard and Princeton. Tim's mentor, Martin Schwarzschild, had given us good advice to take the steepest trajectory early on in one's career to have more options later on, even if that meant living apart in two places for a number of years. John Bahcall kindly gave me a visiting position at the Institute for Advanced Study, but after 2.5 years we had enough of the long commute. I then obtained an NSF visiting professorship for women to spend a year at the astrophysics department of Princeton University, getting there also my first taste of lecturing. Several of my most cited papers were written in this period, most notably on CO photodissociation in 1988 and H2 excitation in 1987, both with John Black. We also defined in 1989 a new type of clouds, translucent clouds, as the transition between the traditionally studied diffuse and dense clouds. These clouds, which are rich in H2 but poor in CO, became known as 'CO-dark clouds' decades later.

By early 1988, we started to look for faculty positions. Several places were interested in both of us, but none of them was an optimal match. I was then encouraged by the California Institute for Technology to apply for one of their cosmochemistry positions, a new line of research initiated by Gerald Wasserburg in the Geology and Planetary Sciences (GPS) department. The first hire was Geoffrey Blake, like me a chemist-turned-astronomer, and it was clear that our scientific interests matched well. Thus I became the first female faculty member in GPS. My two-year stay at Caltech was formative in switching to planetary system formation and learning how big science was done. Tom Phillips introduced me to hands-on submillimeter observations at the new Caltech Submillimeter Observatory (CSO), gradually shifting my interests from diffuse and translucent clouds to the denser star-forming regions of the interstellar medium. Within GPS, David Stevenson stimulated Geoff Blake and myself to put our astrochemical studies in the context of solar system formation, which led to decades long joint observing programs. Most astrochemistry studies had so far focused on the bright and massive Orion star-forming region, but an interesting low-mass source, IRAS16293-2422, had just been identified and proved to be a goldmine for determining the chemical inventory of an analog of our own young Solar System. The latest ALMA results show the source to be even chemically richer than expected.

In 1990, Tim received an offer from Leiden to become professor of theoretical astronomy. I was offered a senior lectureship (equivalent of associate professor with tenure), together with a big personal grant to start a group. Moreover, Thijs de Graauw had offered me some guaranteed time on the Short-Wavelength Spectrometer (SWS) on the Infrared Space Observatory (ISO), an ESA mission that would for the first time obtain infrared spectra of astronomical objects unhindered by the Earth's atmosphere. As hard as it was to leave Caltech, going back to Leiden proved to be a unique scientific opportunity.

So far, my research had focused on gaseous molecular processes, which can be described and computed accurately by the laws of quantum mechanics. However, in cold and dense regions the atoms and molecules freeze-out onto the tiny dust particles, where chemical reactions can take place that normally do not happen in cold gas, such as hydrogenation reactions and producing complex molecules under the influence of UV irradiation. Leiden had in fact pioneered this area by attracting Mayo Greenberg in 1975, who established the first laboratory astrophysics group as a joint Leiden physics-astronomy program. Although I had contacts with the Greenberg lab in the 1980s, grain surface chemistry was too 'messy' for my taste then. However, with the prospect of the upcoming ISO mission, it was clear that the lab data would be crucial for the interpretation of the ice spectra. Greenberg had however retired in 1992 and neither physics nor astronomy wanted to commit to a new hire. The only option was to take the lab under my scientific responsibility, with two senior postdocs, Willem Schutte and Pascale Ehrenfreund, responsible for the day-to-day operation. Together they ran many key experiments and established the first version of the Leiden ice database which would be widely used by astronomers and highly cited.

Two key developments made a longer term commitment to the lab possible. First, Raymond and Beverly Sackler made a donation to the lab. Second, the Netherlands Research School for

Astronomy (NOVA), the alliance of all university astronomy institutes in the Netherlands, received a major 10-year grant in 1998 for new instrumental programs. The lab was fortunate to receive funding for starting two new experiments, taking the lab in a new direction by using ultra-high vacuum techniques from surface science to study the underlying chemical reactions on icy surfaces and their dependence on physical parameters. Harold Linnartz took over the lab in 2005, and under his energetic leadership the lab has blossomed and further expanded. I stayed closely involved through joint PhD students, and providing the link with observations. A beautiful example is the combined laboratory-modeling-observational study of the formation of water from reactions of H with O, O2 and O3, testing routes that Xander Tielens had proposed 30 years earlier. Similarly the hydrogenation of CO to form CH3OH (methanol) has been demonstrated in the lab and shown to be a key step in making even more complex organic molecules like glycolaldehyde (a simple sugar), glycolaldehyde and tri-carbon species like glycerol now being observed with ALMA and also seen in comets. The lab has also trained a next generation of laboratory astrophysicists, most notably Karin Öberg.

Over the past decades, the overarching science goal of my group has been to follow the physics and chemistry from star-forming clouds to planet-forming disks. It has been my joy and privilege to have (co-)supervised a very talented set of nearly 80 graduate students and postdocs. Much of my success is to their credit, their hard work and creativity. Progress is driven by major new advances in instrumentation, so projects were centered every 5 years around a new facility at infrared or millimeter wavelengths where molecules have their primary transitions. Following ISO, I co-led several major observational programs on the James Clerk Maxwell Telescope, the European Southern Observatory (ESO) Very Large Telescope, the Spitzer Space Telescope, Herschel and ALMA. Together these instruments allow us to zoom in on future solar systems, from scales of a few thousand AU in the 1980s to scales of just a few AU today (1 AU=distance Sun-Earth, the orbit of Neptune is around 30 AU). The 'golden triangle' of combining these observations with models and laboratory experiments (including quantum chemistry) inhouse was a further key to the success.

With JCMT, VLT and most notably Spitzer, studies of samples of low- and high-mass protostars became possible. How typical was IRAS16293-2422 and what were the similarities and differences with high-mass protostars like Orion? Much of this research culminated in three ARAA reviews, in 1998 (with Geoff Blake), 2003 and 2009 (with Eric Herbst). We also started to probe the chemistry in protoplanetary disks, and established their 'sandwich' chemical structure with Yuri Aikawa (Japan). Tools for computing the molecular excitation and line radiative transfer needed for the analysis of the data were developed, allowing us to obtain quantitative (rather than qualitative) results; their public release and the molecular data base have served the worldwide astrophysical community up to today.

When I returned to Europe in 1990, I was asked by Reinhard Genzel (MPE) to join the ESA Herschel Science team. This cornerstone mission was finally approved in 1998 and launched in 2009. I was fortunate to lead the 'Water in Star-forming regions with Herschel' (WISH) key program, a collaboration of some 70 scientists across the world. The main goal was to follow the trail of water (a key ingredient for life elsewhere in the Universe) from its formation in cold clouds to its incorporation into disks and ultimately planets. We enjoyed a wonderful collaborative team spirit, especially once the Herschel data started to 'rain' in 2010.

This was also a period of significant personal changes: Tim was offered his dream position, to become the Director General of ESO starting in 2007. With headquarters in Garching near Munich, this meant that we had to face once again the challenge of living in two places at a time when my aging mother needed more care. Fortunately, Genzel kindly offered me a visiting position at MPE, which proved very fruitful in the Herschel and ALMA era.

It was clear since the early 1980s that a new generation of millimeter interferometers was needed to zoom in on solar system scales. In 1993, I was asked to serve on the US scientific advisory committee of their next generation Millimeter Array. At the same time, Europe was developing the concept of the Large Southern Array. It became clear by the mid 1990s that neither continent would have the resources to put together an array powerful enough to address the top-level science goals. Scientists involved in discussions on both sides of the ocean like myself managed to convince the NSF and ESO to join forces in 1997 to build ALMA; the Japanese joined a few years later. ALMA thus became the first modern world-wide collaboration in astronomy. Making ALMA into a reality became a major part of my efforts in the early 2000s, first as member and chair of the ALMA Science Advisory Committee (ASAC, 1999-2005) and later as member of the ALMA Board (2006-2012). Moreover, the then ESO Director General Catherine Cesarsky asked me to step in during 2001-2002 as interim European Project Scientist to help guide the project and set the specifications. This included Band 9 (650 GHz) as a first-light receiver, the development and construction of which was led by NOVA using technology from Herschel. ALMA finally opened its scientific eyes in 2012, with data quality that exceeded everyone's expectation, with our favorite low-mass protostar IRAS16293-2422 as one of the first targets.

ALMA continues to surprise us. Our first ALMA image of a transitional disk with an inner dust cavty was utterly surprising: instead of a full dust ring, we found a highly asymmetric cashew nut-shaped feature offset from the star. What we had found was the first observational evidence for a dust trap created by a gas pressure maximum likely due to an embedded planet. These traps provide a location where tiny dust grains can grow to comet-sized bodies. Another ALMA surprise is that the gas lines in disks are much weaker than expected. Either disks have gas/dust mass ratios much lower than the canonical value of 100, or CO has been transformed into other species like methanol and CO2, as demonstrated in the lab.

The next chapter in our field is JWST, with which I have been associated since 1997. Riding on the success of ISO, we saw an opportunity to convince NASA and ESA to include a mid-infrared instrument, MIRI. As Dutch co-PI, I was heavily involved in the building of MIRI in 2000-2010 and am looking forward to first data in late 2021. MIRI will allow us to make the link from disks to planets, the logical next step after the clouds to disks trail.

Throughout my career I have been fortunate to receive many prizes and major grants at critical moments that have allowed my group to harvest the science from new instruments and embark on risky projects. Much thanks goes to NWO, ERC, KNAW, Leiden and MPE. My hobbies continue to include reading, cooking, camping, hiking, skiing and art, especially links between astronomy and art.

Administration is an inevitable part of scientific life, but can also be seen as an opportunity to advance the field. I succeeded Tim as scientific director of NOVA in 2007, and will become president of the IAU in August 2018. I look forward to stimulating astronomy and its benefits to society worldwide and remind people that we all live on a small planet under the same beautiful starry sky.