Profile of Ewine F. van Dishoeck

The infinite vastness of space, the infinitesimal compactness of a single molecule; comprehending the size of either object can be mind-boggling, and understanding the nature of either can be a life's work. Yet for the past 25 years, astrophysicist Ewine van Dishoeck has made a career of bridging the gap between space and the single molecule. As Professor of Molecular Astrophysics at the University of Leiden (Leiden, The Netherlands) as well as director of Leiden's Raymond and Beverly Sackler Laboratory for Astrophysics, van Dishoeck has spent her career studying the chemistry and evolution of the myriad molecules sprinkled throughout the universe.

Of particular interest to her are interstellar clouds, regions that appear jet black in optical wavelengths but are densely packed with the raw materials that give birth to stars and planets. Along with a multitude of collaborators in Europe and the United States, van Dishoeck, elected to the National Academy of Sciences as a foreign associate in 2001, has studied the chemical evolution of the molecules within these clouds as they condense into stellar and planetary bodies. As summarized in her Inaugural Article in this issue of PNAS (1), which is also part of a Special Feature on Interstellar Chemistry, recent improvements in astronomical instrumentation have enabled van Dishoeck and other molecular astrophysicists to observe in detail low-mass protostellar regions similar to those around the Earth's primitive sun, thus providing some of the first clues about the chemical origin of the solar system.

A Not-So-Chance Encounter

Although born and raised in Leiden, van Dishoeck's brief stopover in the United States as a youth launched her scientific journey. When she was 12, her father, a recently retired professor of ear, nose, and throat medicine, was invited to spend 6 months in San Diego, CA. van Dishoeck took her first science class in the San Diego public school system. She remembers that her science teacher, who as a female and African-American in the 1960s had undoubtedly overcome some obstacles to reach her position, did an outstanding job of fostering in van Dishoeck an interest in science and providing career inspiration. When van Dishoeck returned to The Netherlands, her high school chemistry teacher opened up the wonderful world of molecules for her, and she went on to study chemistry at the University of Leiden.

Ewine van Dishoeck

At Leiden, van Dishoeck found that physics interested her, and her interests began shifting toward chemical physics, and especially quantum chemistry, on which she did her senior project. van Dishoeck was determined to continue with quantum chemistry in graduate school, but soon after she started, the professor who specialized in quantum chemistry at Leiden died. "The way [Ph.D. programs] work in Holland is that you can only do a thesis under a full professor," says van Dishoeck, "and it became clear that the university wouldn't come to a consensus on a replacement for quite some time." Thus, if van Dishoeck wanted to stay at Leiden for her graduate work, she needed to find another field of study.

At that time, van Dishoeck's boyfriend, Tim de Zeeuw, was studying astronomy and had just finished a course on the interstellar medium and the recent discoveries of interstellar molecules. van Dishoeck recalls that he told her, "Well, isn't this something for you?!" van Dishoeck knew nothing about astronomy but learned that the preeminent expert of the interstellar medium was Alex Dalgarno at Harvard University (Cambridge, MA). That summer, as fate or fortune would have it, van Dishoeck and her boyfriend were camping in Canada's Mont Tremblant National Park and heard that the park was hosting a major astronomy conference. "We got up the courage to go up to this conference and see if Professor Dalgarno was there," she says. Dalgarno was indeed present, and after a brief, pleasant conversation, he invited van Dishoeck to study with him at Harvard for a few months, which she did in 1980 after receiving her master's degree in chemistry from Leiden. "And that period was enough for the Dutch authorities to give me a grant to do research in this field, even though there wasn't formally a professor in that field," she says.

East to West Coast

Upon completing her Ph.D. thesis on photodissociation and excitation of interstellar molecules in 1984, van Dishoeck received one of Harvard's Society of Fellows positions, which allowed her to continue her research in Dalgarno's laboratory, where she had made frequent visits while completing her degree. The opportunity presented a small problem, however, in that de Zeeuw, whom she had recently married, received a fellowship at the Institute for Advanced Study in Princeton, NJ. "Interestingly, we had the opportunity to have two positions in the Princeton area or two positions in the Harvard area," she says, "but the advice we got from some of the more senior people was that in the long run, it's better at the earlier stages to take the steepest road in terms of your career so that later on you have the better papers to be together in one place." And because Harvard was the best place for van Dishoeck, and Princeton the best place for her husband, they decided to live apart for the time being.

At Harvard, van Dishoeck's work was principally a continuation of her thesis project, studying the photodissociation of molecules in interstellar clouds or comets (2–4). She studied "how rapidly a molecule falls apart under UV radiation and what are the basic molecular processes by which this occurs," she says. "We know this process from our own atmosphere and ozone. There's a prime example of a molecule that is photodissociated into an oxygen molecule and an oxygen atom, which then, of course, is a large cause for the ozone hole."

van Dishoeck also studied molecules as diagnostic tools for studying certain processes in interstellar clouds. "For example, if you look at the beautiful nebulae in the sky, you want to know how warm or how dense they are," she says. "So we spent some time looking at the excitation of various molecules

This is a Profile of a recently elected member of the National Academy of Sciences to accompany the member's Inaugural Article on page 12249.

van Dishoeck, with husband Tim de Zeeuw, in front of the APEX 12-m telescope, Atacama Large Millimeter Array (ALMA) site, Chajnantor, Chile, 2005.

because the ratios can tell you about how often and how hard a molecule collides." In turn, van Dishoeck notes, these values could be related to molecular parameters, and so these molecules could be turned into long-distance thermometers and pressure gauges, thus allowing for the design of comprehensive models of these clouds (5).

After her Fellows program concluded, van Dishoeck reunited with her husband at Princeton for one year as a visiting professor, "which was very nice. Certainly after two and a half years, we had more than enough of this commuting!" she says. In 1988, van Dishoeck and her husband moved to the West Coast, where she accepted a faculty position at the California Institute of Technology (CalTech, Pasadena, CA) in a new program: cosmochemistry, a subset of the geology and planetary sciences department. At CalTech, van Dishoeck began expanding her work to a third line of research, by using molecular diagnostics to study the different stages of star and planet formation to understand how these stellar bodies are born. This field had just opened up after the completion of powerful new ground-based telescopes, such as the CalTech Submillimeter Observatory and the James Clerk Maxwell Telescope (JCMT). "These regions in which stars and planets are being formed are basically very dusty," she explains, "and that means they are completely black at the optical range. It's only when you go to longer wavelengths that you start to find something."

Return to Holland

van Dishoeck spent two fruitful years at CalTech, but in 1990, her husband was offered a full professorship at the University of Leiden. van Dishoeck was offered an associate-level position at Leiden, one that included many grants to help start her own research group. "Both of us really enjoyed the United States, and I certainly would have loved to stay a little bit longer at CalTech," she says of the tough decision to return home, "but [Leiden's] combination was attractive enough for the two of us to move back. I'm still a very frequent visitor to CalTech and Harvard, [and] I still have very good collaborations there."

She adds that there was one other major reason for coming back to The Netherlands: the European Space Agency (ESA) was set to launch a new satellite, the Infrared Space Observatory (ISO). "That was important because in infrared wavelengths, you can see not just gas-phase molecules but also solid-state species," she says. "That gave me an infrared complement to what I was doing at the submillimeter telescopes, which was important since a lot of molecules are freezing out on to the grains in the cold parts and then coming off again in the warmer part and triggering a rich gas-phase chemistry. You need both wavelengths to put the story together." One of the four instruments on board, the Short Wavelength Spectrometer, had been built in The Netherlands. The principal investigator for that project, Thijs de Graauw, had guaranteed time on the satellite, and he kindly offered some time to van Dishoeck.

The ISO was scheduled to launch in 1992, but as is common with such space projects, multiple delays pushed the launch to 1995. The delay was actually a blessing in disguise. In 1992, Mayo Greenberg, who had set up Leiden's first astrophysics laboratory in the 1970s, reached the mandatory retirement age of 70. At the time, van Dishoeck felt it was important to keep the astrophysics laboratory up and running. "The ball sort of got in the court of astronomy, and they turned to me and said, 'Well, Ewine, is this something for you to take under your wing?' and I said, 'Well, I'm not really a laboratory person,' but I could see that [Greenberg's] lab was set up to do exactly the kind of experiments that we needed to do in order to interpret the data from the ISO satellite." So, by scraping money together from various sources, van Dishoeck took over the laboratory and kept it going for several more productive years, while she collected her first observations from the ISO satellite.

"We were able to identify several new species in the solid state and at the same time learn more about the chemical evolution of these regions in which new stars are being formed," she says.

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Some of the highlights included carbon dioxide, methane, and formic acid ices, which are extremely difficult to detect from ground observatories because of interference by these molecules in Earth's atmosphere (6–8). van Dishoeck and colleagues also found hot water and carbon dioxide gas, as well as some unusual gaseous compounds, such as the methyl radical (CH_3), an intermediate product in reactions involved in hydrocarbon synthesis (9–11). CH_3, which is extremely reactive and unstable on Earth, had been studied by Nobel laureate Gerhard Herzberg in the 1950s. "He had always said that these are the kinds of molecules you would see in outer space, but it wasn't until we got the infrared spectrum that we were finally able to identify it," says van Dishoeck.

Finding Baby Planets

van Dishoeck's work on stellar evolution, as well as that of other researchers, was interesting in its own right but was not considered particularly relevant by some because the results could not be related to Earth's solar system. "With the ISO satellite, we only had the sensitivity to look at high-mass stars, like those in Orion, which are 10,000 times more luminous than the sun," explains van Dishoeck. "Our star is just a very ordinary star." Over the past 5 years, however, technology has improved to be sensitive enough to study the chemistry of low-mass stars like the sun as well as even smaller objects such as brown dwarfs that are not massive enough to ignite hydrogen and become true stars. "So that is the new part of the story," van Dishoeck says. She reviews some of the recent contributions to this story in her PNAS Inaugural Article (1).

Many of the findings in van Dishoeck's Inaugural Article are connected with the Spitzer Space Telescope, NASA's successor to the ISO that was launched, again after a lengthy delay from the original planned date, in 2003. "I am fortunate to be part of one of these big legacy programs in which you give a group of people, in my case a group led by Neal Evans from the University of Texas, a large amount of observation time with the caveat that your data become public immediately," she says. "So it's basically a program you're carrying out for the community." One of the main objectives of Evans' group was to survey and map the nearby large molecular clouds, such as in the Chameleon and Perseus star systems. This work helped uncover additional protostars lurking in the darkness, such as the newborn star HH 46/47 within the Vela constellation (12), which was one of the Spitzer Space Telescope's earliest discoveries.

The high sensitivity of the Spitzer Space Telescope also allows for a better glimpse of the icy and dusty disks that rotate around newly forming stars as they collapse, rings that may someday condense into planets. These protoplanetary disks have been difficult to study because they have far less mass than the star they orbit, and depending on their angle, can obscure the star light. van Dishoeck and colleagues managed to study some potential protoplanetary disks with fortunate alignments and found interesting characteristics. In addition to some of the first discoveries of water, ammonium, and methane ices in these disks (13), she and her group have also found large amounts of hydrogen cyanide (HCN) and acetylene (C_2H_2) gases, both of which are building blocks for some of life's essential compounds: amino acids and nucleic acids (14).

Although the presence of these prebiotic molecules should not receive too much hype, according to van Dishoeck, she believes that these protoplanetary disks, especially around low-mass stars, represent the future of interstellar chemistry research once the technology to observe these tiny objects, by galactic standards, is available. Besides the Spitzer Space Telescope, such technologies will soon be on the way. One such instrument on the horizon is the Herschel Space Observatory, with which van Dishoeck has been involved for many years. "Herschel will be looking in the far infrared spectrum and will be particularly well suited to look for water, which is a key molecule in all of chemistry," she says. "That's another future line of research, the chemical evolution of water. Where does it form, where does it freeze out as ice, and where does it get back into the gas phase?"

van Dishoeck has also been extensively involved in planning other next-generation instruments, such as the Atacama Large Millimeter Array (ALMA) in Chile. ALMA will combine 50 single telescopic dishes to act as one. Further down the road, the James Webb Space Telescope will eventually succeed the Hubble. "So that is sort of the balance that you now have. When you are a young student or a postdoc, you're fortunate that other people have put in the time to promote these instruments with which you can do your research, and now our generation has to be the drive for the facilities with which future students can do their research," says van Dishoeck. Such a forward-thinking perspective is important because these large astronomical facilities usually take 20–25 years to advance from conception to fruition. "For example, for the Herschel Space Observatory, I had my first meeting on it in 1982, when I was still a graduate student," says van Dishoeck. Now, years later, the Herschel is set for a 2008 launch date—barring any unexpected delays, of course.

Nick Zagorski, *Science Writer*

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