A WISH come true:

Water In Star-forming

Water is one of the most important molecules, not only for life on Earth, but also for tracing energetic processes in space. Interstellar space consists of two ingredients: gas and tiny speckles of dust. In cold, dark gas clouds the dust grains are covered with many layers of ice consisting of various molecules. Whenever energy is dumped into a cloud, the ice will evaporate and become vapour, and thus increasing the gas-phase abundance by many orders of magnitude. In this respect, water can act as a "switch" that turns on. One of the reasons these dark, molecular clouds are interesting is that they are also the birthplaces of stars like our Sun. Thus, by observing water vapour, it is possible to trace where and how much energy new-born stars inject into their surroundings.

BY LARS KRISTENSEN

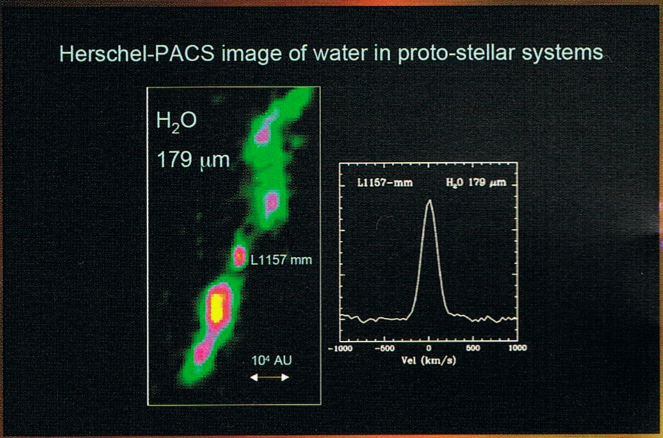

Figure 1: Examples of water emission lines observed towards a low-mass star-forming region in Perseus. The velocity of the emitting water vapour has been measured using the Doppler effect. The emission is tracing water moving at up to 70 km/s.

To investigate the role of water, the Herschel Space Observatory was launched on May 14 2009 from French Guyana. Herschel is the biggest space telescope ever built, with a single mirror measuring 3.5 m in diameter, more than 1 m bigger than that of the Hubble Space Telescope. Its three instruments provide imaging and spectroscopic capabilities in the 50-500 µm wavelength range, one of the last unexplored regions of the electromagnetic spectrum in space. Herschel is currently in orbit 1.5 million km from Earth and from there providing a unique eye to the Universe. The reason it needs to be in space is exactly because of the questions it aims to answer: water. The Earth's atmosphere is full of water vapour, even at very high altitudes, making it nearly impossible to observe outside of the atmosphere at far-infrared wavelengths. The water vapour simply absorbs any emission from interstellar water vapour. Therefore, to observe water and quantify its role through the star-formation process, it is necessary to make observations from space.

regions with Herschel

The goal of the "Water in Star-forming regions with Herschel" (WISH) key programme is to trace all of these physical and chemical processes across various sources with a range in mass and evolutionary stage ('time'). The programme is led from Leiden Observatory (Ewine van Dishoeck, Principal Investigator; PI) with several staff members, post-docs and PhD-students involved in observations of water and related molecules in star-forming regions. Besides measuring the energetics, one of the aims is to follow the "water trail" of star formation from prestellar cores, where the gas cloud has not yet begun to collapse on itself, to protostars that accrete gas from the surrounding envelope, to disks around young stars, where comets and planets are forming.

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Star formation takes place deep inside dark, molecular clouds, and observing molecules directly is often the only way to gain information of the physical conditions, such as temperature and density structure. Because of differences in molecular structure, each molecule has an individual "fingerprint" in the form of different spectral emission lines belonging to that particular molecule. The intensity of these emission lines is what provides astronomers with information regarding the physical conditions. In this respect, water is again a unique molecule, since it is very susceptible to changes in temperature and density, and therefore a spectrum of water lines will reflect the actual physical conditions.

Another way of gaining insight into the star-formation process is to measure directly how fast the gas is moving. In the colder part of the cloud, the gas is not expected to move much, maybe 1-2 km/s. It is possible to measure the velocity by means of the Doppler technique, provided that instruments are available to measure very accurately the wavelength of light. Such an instrument is HIFI (Heterodyne Instrument for the Far-Infrared) on Herschel, built by an international consortium under the leadership of the Netherlands Institute for Space Research (SRON) with Thijs de Graauw (Leiden adjunct professor) as the PI. The current PI is Frank Helmich, a former Leiden PhD student. With HIFI, it is possible to measure the velocity with a precision down to 0.1 km/s.

As an example, in the constellation of Perseus, at a distance of 750 light-years from the Earth, several stars like the Sun are forming right now. Through observations of water, it has proven possible to disentangle and quantify some of the energetic processes taking place there. Results are still being interpreted, but it seems that water is tracing unusually fast-moving gas, up to 70 km/s. This indicates that the emission from water is well suited for tracing the more energetic parts of the star-formation process. At the same time, the total amount of water in all parts of the protostellar system is being measured, including the disk from which planets like the Earth can form. Preliminary results indicate that there is very little water vapor in the outer regions of disks (beyond 40 Astronomical Units, equivalent to the orbit of Pluto in our solar system) but enough water to fill 10,000 Pacific Oceans in the inner disks.

Another example is shown in Figure 2. The image shows water emission appearing from the central protostar in the form of large-scale outflows extending over almost a light-year. These outflows are caused by fast-moving material that is being expelled from the central protostar at velocities greater than 100 km/s, leading to shock waves in the interstellar medium. As the shock waves impact the surrounding cloud material, they dump large amounts of energy into the gas and dust, thus evaporating and releasing the water into the gas phase, where astronomers can observe it. Furthermore, water vapour emission is seen to be strong around the protostar itself. A possible reason for this is that UV- and X-ray emission from the star is heating up the gas and dust particles causing the water to evaporate. This particular young star is very similar to what the Sun looked like 5000 million years ago, and the young Solar System likely went through a similar phase.

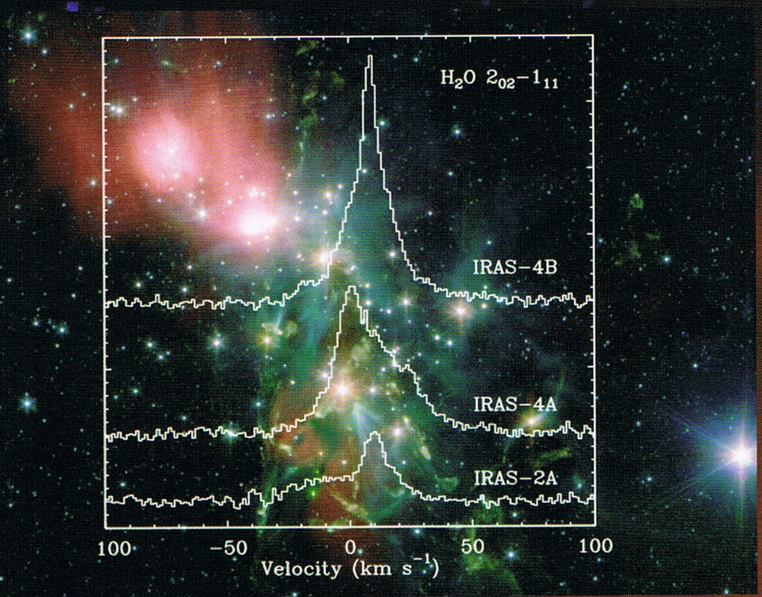

Figure 2: The molecular outflow of L1157, a solar-type young star that is currently forming. The colours trace where energy is being deposited into the surrounding cloud material. This happens in the form of large-scale shocks moving at up to 100 km/s. At the same time, the protostar itself is being lit up by water emission, indicating that something extreme is taking place here. The actual mechanism is still not well understood. The image covers 0.5 lightyears in size.

When looking towards the more evolved phase of star formation, where the star has formed a disk from which planets will form, water vapour appears to have gone missing. This is in contrast to the disks at earlier evolutionary stages, where there is plenty of water vapour. This result came as a surprise, and it is currently not understood where the water vapour has gone. One possibility is that the water-ice-covered dust grains stick together very well, in essence forming large, dirty snowballs. These snowballs will then fall towards the centre of the disk because of gravity. Water is less likely to evaporate from larger grains, because the surface area is relatively smaller. Furthermore, when the large grains sink towards the centre of the disk, they are exposed to much less light and heat from the star, something which will also prevent it from evaporating. More work is required to test whether this theory is true, or whether other explanations are possible.

From these preliminary results, it is evident that star formation is a much more violent and energetic process than previously believed. Forming a star is not simply a matter of letting gas collapse onto a central object, but an energetic and dynamical process where gas is also being expelled from the protostar at more than 100 km/s. At the same time, the gas is exposed to strong UV- and X-ray photons that also heat up the gas. With observations of water and complementary data obtained from ground-based telescopes, it will be possible to quantify these processes for the first time, thus providing a lasting legacy for astronomers and for the public.

For more information, see the WISH website at http://www.strw.leidenuniv.nl/WISH

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