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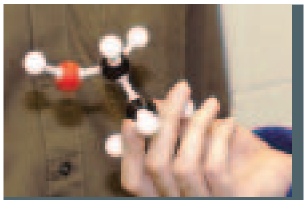
CHASING MOLECULES IN THE SPACE BETWEEN THE STARS



Ethanol molecule

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While molecules are usually thought of as the material in laboratories with which chemists work, the last three decades have revealed that the Milky Way, as well as other galaxies in the universe, have a significant component of molecular material in the space between their stars. Most important, it is from very cold, dense interstellar clouds that new stars and solar systems, such as our own, are formed.

Molecules play a key role in the structure and evolution of galaxies, stars, and planets. Yet, it was a great surprise to discover that molecules exist in the very harsh environment of interstellar space. How do these fragile groups of atoms survive the flux of high-energy particles and the intense ultraviolet radiation from stars? How are they formed when the temperature is only 10 degrees above absolute zero? Models predicted that there would be hardly any reactions that could make even simple molecules, much less the 100 or so different molecules that have now been found in interstellar clouds, ranging from such simple ones as carbon monoxide (CO) and water (H_2O), to improbably complicated and terrestrially rare species as $HC_{11}N$.

Kevin Wong (l.) is holding a model of dimethyl ether, found in space, while Peter Hall (r.), holding a model of ethanol molecule, ponders how it is made in interstellar space.

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Astronomers now recognize that the rich chemistry in interstellar space is made possible by the shielding action of interstellar dust grains, which absorb ultraviolet radiation. Inside these molecular clouds, a type of chemistry based on reactions between charged particles (ions) and neutral atoms and molecules proceeds even at low temperatures. Over the past decades, laboratory measurements of key reactions have enabled the building of time-dependent models for interstellar cloud chemistry. This is what Peter F. Hall, research associate, did in his Ph.D. thesis at the University of Manchester Institute of Science and Technology.

The Molecular Cloud Group

- Paul Goldsmith, James A. Weeks Professor in the Physical Sciences, Astronomy, heads the Molecular Cloud Group, studying key physical conditions and star formation in interstellar clouds.
- Peter Hall, a postdoctoral research associate in Astronomy, has built time-dependent models for interstellar cloud chemistry using laboratory measurements of key reactions.
- Kevin Wong, an undergraduate researcher and chemistry major, studies less dense clouds at high galactic latitudes, which is a "testbed" for determining how well researchers understand the chemistry in regions where ultraviolet radiation gets in.
- Yvonne Tang, a graduate student in Applied and Engineering Physics, studies the Taurus molecular cloud complex, one of the nearest regions of low-mass star formation.
- Jagadheep Pandian, a graduate student in Astronomy, studies masers in space, particularly the methanol molecule which exhibits very strong maser emission from regions in which massive stars have very recently formed.

Now at Cornell, Hall shares this expertise with the Molecular Cloud Group, working particularly with Kevin G. Wong, an undergraduate chemistry major. When Wong took a class in astrophysics (Astronomy 332) taught by Paul F. Goldsmith, Astronomy, he was intrigued by the very different chemistry from that which he had encountered in the standard curriculum. Wong volunteered for a research project during the summer of 2003 and worked with Hall's computer code to examine the basic features of interstellar chemical evolution. Now, he is focusing on less dense clouds at high galactic latitudes, which are another "testbed" for determining how well the researchers understand the chemistry in regions where a limited amount of ultraviolet radiation gets in.

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Molecules trace many vital aspects of material in our galaxy that forms "the interstellar medium." This is the material that is not in stars, but from which new stars form, and which is replenished by the mass that is lost from stars at the end of their life. One very useful probe is maser emission—microwave amplification by stimulated emission of radiation—which is the direct precursor of the ubiquitous laser; it is the same idea working at much shorter wavelengths. The first maser was built in the laboratory by Charles Townes in 1954, but naturally occurring masers, which are stupendously powerful emitters of radio frequency radiation, were first noticed in 1965. Masers in space have now been found in a variety of molecular species, and of particular interest is the methanol molecule (CH_3OH), which exhibits very strong maser emission from regions in which massive stars have very recently formed.

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Kevin Wong (l.) and Peter Hall (r.) with a model of ethanol molecule

Studying these masers is the research and thesis topic of astronomy graduate student, Jagadheep D. Pandian. However, before he could start observing, he had to build a special low-noise receiver for the Arecibo telescope that works at the methanol maser frequency. This work took full advantage of Pandian's training in electrical engineering and is now almost complete; in a few months, he will start observations at Arecibo. For his Ph.D. degree, Pandian plans to survey a substantial part of the plane of the Milky Way visible from Arecibo and compile the most complete catalog of methanol masers. This will allow him to probe regions of massive star formation and also to delineate their locations in the spiral arms of the Milky Way.

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Kevin Wong (l.) and Paul Goldsmith (r.) with a model of HC_5N, a cyanopolyyne (long chain molecule) studied at Arecibo

Molecules can also trace the formation of lower-mass stars, like the Sun, since there are many unanswered questions about their formation. Taking a very intensive look at one of the nearest regions of low-mass star formation—the Taurus molecular cloud complex—is the focus of Yvonne K. Tang, a graduate student in Engineering and Applied Physics. Tang was an undergraduate at Cornell, and she became more and more involved in astronomy in her senior year. She is now preparing to conduct large-scale surveys of Taurus in molecules and in atomic hydrogen, the latter to be carried out with the new ALFA receiver system on the Arecibo telescope.

By comparing the distribution and motions of the atomic and molecular gas in the region, the researchers hope to answer many questions including the following:

- How does the transformation from atomic cloud to molecular cloud take place?
- How long does this process require?
- Does this transformation lead directly to star formation over a large area, or does it only set the stage for the formation of new stars occurring randomly throughout the region?

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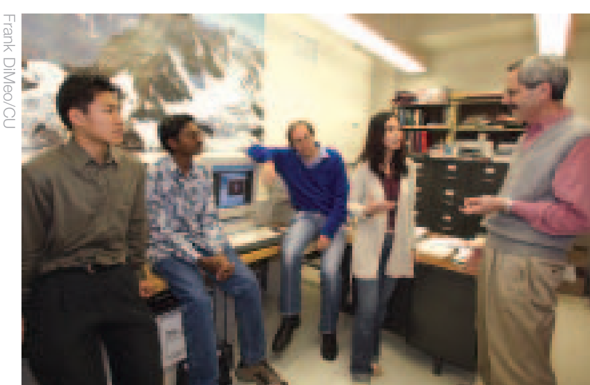
Tang will be gathering data on carbon monoxide, using the radio telescope operated by the University of Massachusetts, Amherst, as well as Arecibo. The task of gathering and analyzing data will be challenging, but the result will provide a unique, new perspective on this phase of evolution of the interstellar medium.



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(l. to r.) Kevin Wong, Jagadheep Pandian, Peter Hall, Yvonne Tang, and Paul Goldsmith all those strange molecules and dust grains could have an important influence on how stars like the sun, and the planetary systems that often accompany them, came to be.

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(l. to r.) Paul Goldsmith, Peter Hall, Yvonne Tang, and Kevin Wong

Paul Goldsmith came to Cornell in 1993, and while serving as director of the National Astronomy and Ionosphere Center (NAIC), he was involved in a number of projects using molecular emission to determine key physical conditions in interstellar clouds. In collaboration with astronomers at the University of Texas, he is studying formaldehyde in the coldest dark clouds. The study suggests that in the densest, central areas of these regions, which may in the future collapse to form stars, the formaldehyde is actually sticking to the surfaces of dust grains.

This finding reinforces one of the key discoveries made by the Submillimeter Wave Astronomy Satellite (SWAS) launched in 1998, for which Goldsmith is a co-investigator. SWAS found that the abundance of two key molecules in interstellar clouds, water and molecular oxygen, were much lower than expected. In particular, O_2, was not detected, and is about a hundred times less abundant than predicted. The best explanation is that grains are "stealing" key molecules from the gas phase. This not only changes the chemistry, but means that molecules like water, which are expected to play a critical role in emitting radiation and cooling clouds and letting them contract to become stars, will do so much less effectively than previously thought.

So all those strange molecules and dust grains could have an important influence on how stars like the Sun, and the planetary systems that often accompany them, came to be.

Paul F. Goldsmith
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