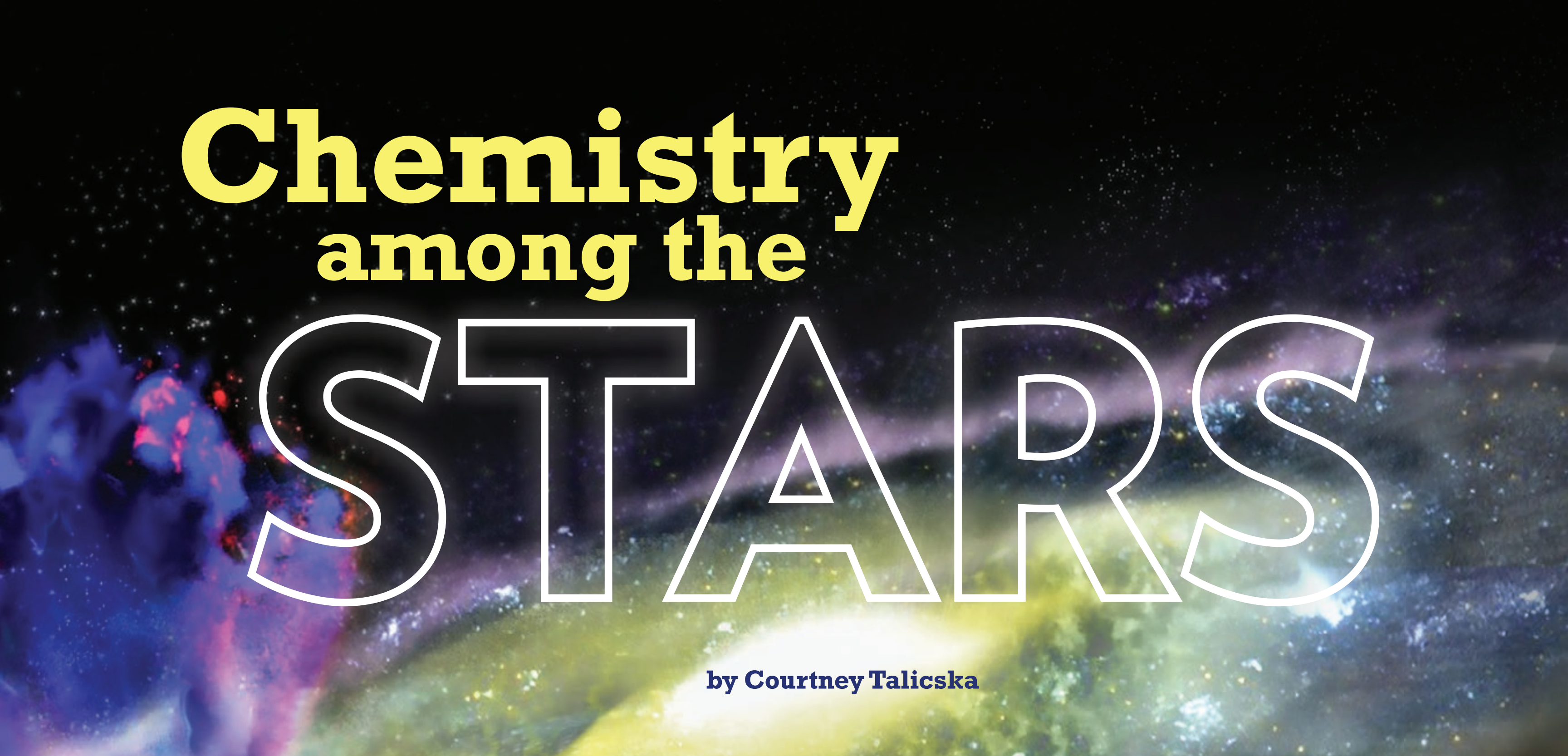
Chemistry among the STARS

by Courtney Talicska



In 2006, scientists used the Green Bank Telescope in West Virginia to discover a superbubble of hydrogen gas rising above the plane of the Milky Way.

BILL SAXTON, NRAO/AUI/NSF

As children, many of us spent hours looking up at the night sky, often in search of constellations such as the Big Dipper, Cassiopeia, and Orion's Belt. Visible with the naked eye, these groups of stars have been well known to humans for millennia. Beginning in the 17th century, astronomers used telescopes to study planets and stars; in the last century, advanced telescopes have allowed us to see even farther.

Until recently, though, something has been missing from scientists' understanding of space. What are those stars—and the space between them—made of?

Spectral Identities

Astrochemistry focuses on the chemical makeup of stars and interstellar space. By investigating compounds present outside our solar system, scientists can better analyze the life cycles of stars, explain the origin of life on Earth, and improve our understanding of how the universe began. However, we are limited in where we can send scientists and spacecraft to collect samples from space; currently there is no way to collect a physical sample from the interstellar medium.

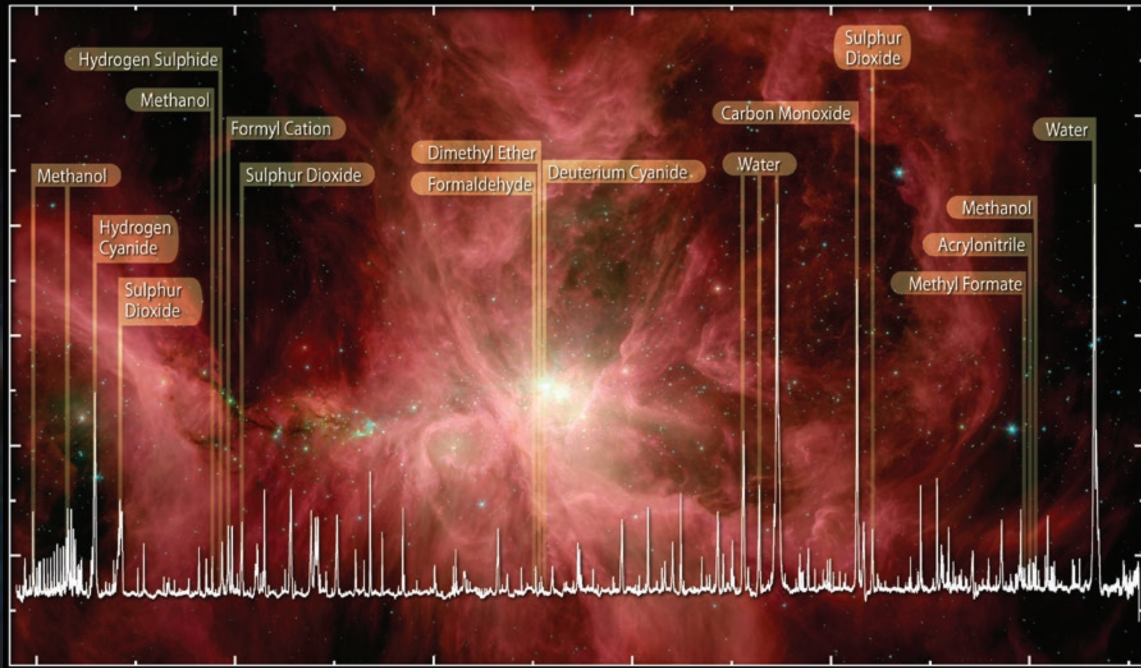
Fortunately, thanks to new telescopes that detect electromagnetic radiation of wavelengths longer than visible light, scientists can collect chemical data from stars and interstellar space without leaving Earth.

Every molecule has characteristic movements that correspond to certain wavelengths of electromagnetic radiation. For example, the amount of energy required to make a molecule of methane (CH_4) rotate in a specific way corresponds to a single wavelength of light. A slightly different molecule, say methanol (CH_3OH), requires a different amount energy to make it rotate. Once this light energy is absorbed and the molecule's structure or orientation changes, often the molecule then emits electromagnetic radiation of another wavelength. Each molecule has its own unique spectrum—a map of wavelengths of light at which it absorbs and emits energy. Spectra can include both visible light and other electromagnetic radiation such as radio waves, microwaves, infrared, and ultraviolet radiation.

In 1859, Robert Bunsen and Gustav Kirchhoff caused quite a stir in the scientific community when they discovered that radiation emitted from atoms could be mapped to a unique spectrum. Following this discovery, scientists rushed to determine the spectra of many well-known molecules such as methane, ethanol, and water. Libraries of known spectra are immensely useful tools: scientists can determine which molecules are present by matching spectra from their data to thousands of reference spectra. The problem for astrochemists is that reference spectra do not yet exist for all the molecules that may be found in interstellar space.

Mapping Rare Ions

Because of temperature extremes, vacuum-level pressures, and intense stellar radiation in the interstellar medium, scientists expect to find molecules there—such as the ions H_3^+, CH_5^+, and $CH_3OH_2^+$—that are not naturally found in the gentle atmospheric conditions near Earth's surface. Today, astrochemists are interested in determining precise spectra for rare ions such as these.



ESA/NASA/JPL-CALTECH

This spectrum taken by the Herschel Space Observatory shows emission lines from numerous molecules in the interstellar medium. Each line corresponds to a single wavelength of energy on the x-axis, and certain lines are characteristic of certain molecules. By knowing the emission lines and intensities of molecules, scientists are able to identify exactly which lines in the spectrum correspond to which molecules.

This is the focus of researchers in Dr. Ben McCall's lab at the University of Illinois at Urbana-Champaign. Before we can determine the spectra for ions likely to be found in the interstellar medium, though, we have to create them in our lab. We use specialized vacuum chambers and ion sources to create these ions; then, using highly sensitive, high-resolution instruments, we map out the spectra for these ions with extreme precision, pinpointing their exact emission wavelengths. Since our lab focuses mainly on the emission of ions in the infrared region of the electromagnetic spectrum, our results help scientists interpret spectra obtained from infrared telescopes such as the Herschel telescope.

Each dataset from a long-wavelength telescope covers multiple wavelengths of energy, so a spectrum of a given portion of the interstellar medium will show the emissions of many molecules and ions [see figure]. If a molecule or ion emitted radiation at the time the data was collected, this emission appears as a single line on the spectrum. Different molecules and ions emit different intensities of radiation, and these differences correspond to the varying heights of the lines in the spectrum. Since each line corresponds to a single wavelength of energy, you can imagine picking out each line that corresponds to, say, methane. In much the same way, scientists are able to pick out the groups of lines characteristic of certain molecules and ions. This allows scientists to determine what the interstellar medium is made of without collecting a physical sample.

With thousands of compounds present in the universe, scientists have a lot of work ahead in order to create and precisely map the emission wavelengths of ions of interest in controlled laboratory settings.

Seeing Farther

Astrochemistry has seen many breakthroughs in its relatively short history. The first interstellar molecules (CH, CN, CH^+) were detected in the late 1930s. A short time later the hydroxyl radical (OH^-) was detected in the gases surrounding supernova Cassiopeia A using a radio-wavelength telescope. Spurred by this success, scientists scrambled to detect more molecules using radio telescopes. Several years later they found that water, ammonia, and formaldehyde are also present in the interstellar medium. In 1970 radio-astronomy helped prove that carbon monoxide is present in the Orion Nebula. More recently in 2006, scientists used the Green Bank Telescope in West Virginia to discover a hydrogen gas superbubble nearly 23,000 light-years from Earth.

Astrochemical abilities have improved with advances in technology. Improvements in the sensitivities and range capabilities of telescopes have allowed researchers to delve farther and deeper into the mysteries of our universe. In 2008 scientists combined infrared spectroscopic data taken from the Keck II Telescope in Hawaii and NASA's Spitzer Space Telescope to prove the existence of water molecules in the gas around two young stars hundreds of light-years from Earth. In 2009 the Spitzer telescope found evidence of silicate crystals in the interstellar medium around the star EX Lupi, and in December 2013 scientists detected the argon hydride ion in the Crab Nebula about 6,500 light-years from Earth.

As technology continues to improve, new discoveries will undoubtedly be made that will further elucidate the secrets of the interstellar medium. Plans for new, even more powerful telescopes are already in the making. As a future astrochemist, you could study extragalactic molecules—maybe even some from very high red-shift galaxies when the universe was really young. Maybe you'll get the chance to use the future Giant Magellan Telescope or the James Webb Space Telescope to discover an ion that proves that life once existed (or currently exists) far beyond Earth's atmosphere. By building on its rich and informative history, astrochemistry will be instrumental in improving our understanding of things beyond the physical reach of science for years to come. **i**

Courtney Talicska earned her B.S. in chemistry from the University of Michigan and is now in her first year as a graduate student in physical chemistry at the University of Illinois, Urbana-Champaign. She is enjoying working in the McCall Lab and looks forward to the exciting discoveries the lab will make in the coming years. In her free time, she loves to golf, go on bike rides, and read mysteries.