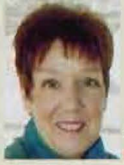
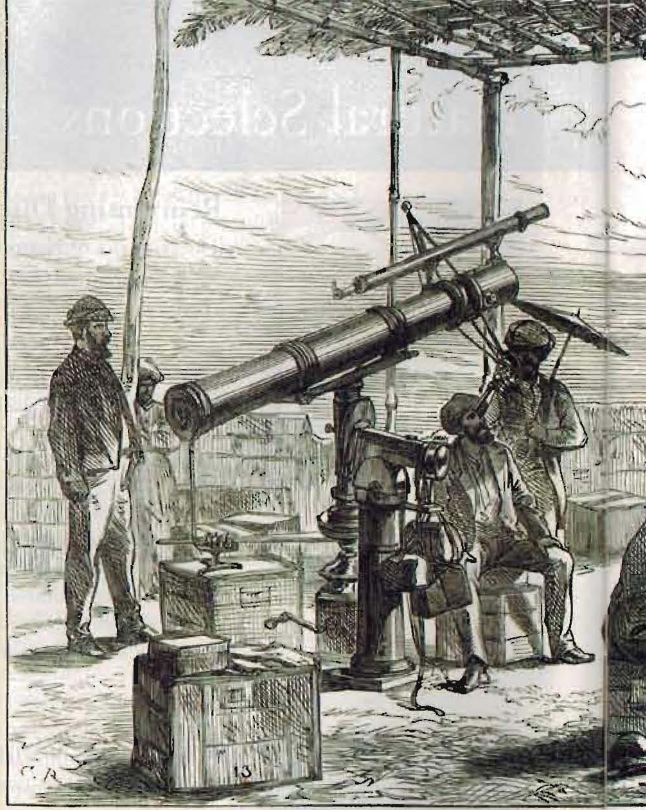


COSMIC BACKGROUND BY MARCIA BARTUSIAK

Chemistry Lesson

How light was thrown on distant matters



In 1999 NASA launched a spacecraft called *Stardust* into the heavens to capture just what its name suggested: matter from outer space that likely originated from stars long dead, stars whose remnants provided the material out of which our solar system formed.

In its years-long journey, eventually covering billions of miles as it orbited the Sun, *Stardust* flew through a stream of interstellar dust, as well as the coma of Comet Wild 2, collecting specks of matter onto its tennis-racket-wide aerogel collector. In 2006 the probe returned to Earth's vicinity and ejected its precious cargo. Safely nestled in a special capsule, the payload landed in Utah's Great Salt Lake desert in the dead of night. Transported to NASA's Johnson Space Center in Houston, Texas, this cosmic treasure—tens of thousands of microscopic and submicroscopic grains—has been under close scrutiny ever since.

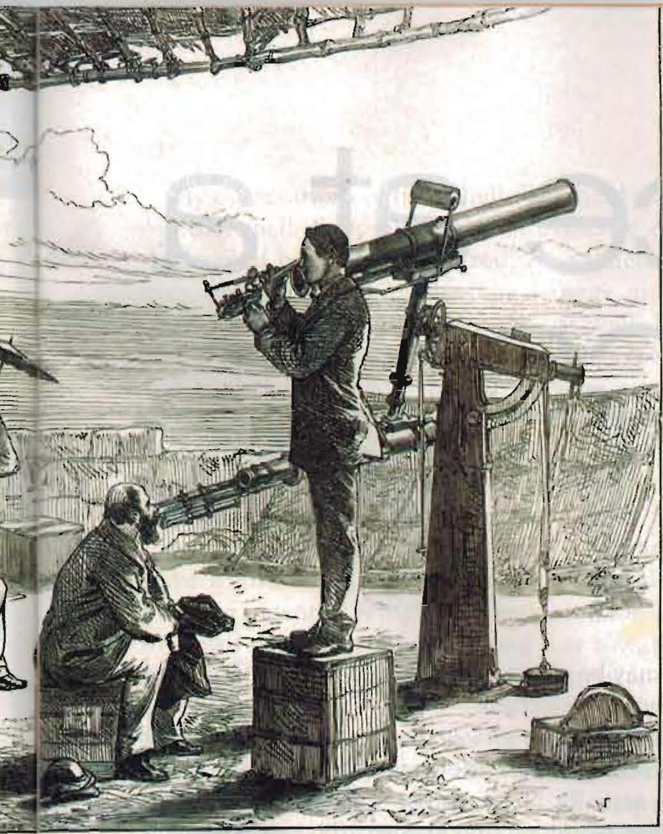
One of the most startling revelations of the dust's analysis was the discovery of glycine, the smallest of the twenty amino acids that serve as vital building blocks for our body's proteins. "The significance of this discovery is that comets must have delivered at least one amino acid to our planet before it had life," said *Stardust* principal investigator Don Brownlee. Other researchers have found nucleic acids, components of DNA and RNA, in meteorites. It's further confirmation that "we are made of starstuff," as Carl Sagan so famously described it in his book *Cosmos*.

That we have such an intimate connection to the cosmos is actually a relatively new revelation. For most of history, astronomers could not be sure that the stuff of the heavens was anything at all like the stuff on Earth. And since outer space was so inaccessible, they figured an answer would be forever out of their reach. The French philosopher Auguste Comte was so confident in this judgment that in 1835 he boldly asserted that "we would never know how to study by any means [the stars' and planets'] chemical composition, or their mineralogical structure." That declaration is one of the most infamous misstatements in the history of science. What Comte did not anticipate was the development of new techniques that—in less than three decades—would sweep away his ill-timed conclusion.

The turnabout primarily happened when Gustav Kirchhoff, a professor of physics at the University of Heidelberg, and chemist Robert Bunsen, creator of the famous laboratory burner, teamed up in 1859 and demonstrated how to identify substances by the specific colors of light they emit during chemical reactions or when burning. Whenever energized and viewed through a spectroscope, each element could be recognized by a unique set of colored lines it displayed.

Soon the two collaborators realized that such spectral fingerprints could be effectively studied whether the light originated from a distance of one foot within a laboratory or from millions of miles away. That insight may have been prompted by a fire that erupted in the nearby city of Mannheim and was visible across the Rhine river plain from their laboratory window. Upon directing their spectroscope at the flames, Kirchhoff and Bunsen discerned the strong green emission of barium in the roaring blaze, as well as the distinctive red signature of strontium. Sometime later, while they were strolling together through the wooded hills near Heidelberg, Bunsen wondered if they could analyze the Sun's light in a comparable fashion. "But people would say we must have gone mad to dream of such a thing," he declared.

Kirchhoff, though, had no such qualms. By 1861 he had turned his spectroscope to the heavens and identified a number of elements in the Sun's atmosphere, including sodium, magnesium, calcium, chromium, iron, nickel, copper, zinc, and barium. Within a few years other astronomers, such as Angelo Secchi in Italy and William Huggins in England, reported finding similar elements in such distant stars as Aldebaran, Betelgeuse, and Sirius. Here was definitive proof that the chemical elements of the Earth were indeed identical to those of the cosmos. The long-standing Aristotelian belief that celestial matter was somehow different from the ter-



PHOTORESEARCHERS

Awaiting the December 12, 1871, solar eclipse in India, Capt. John P. Maclear of the British Royal Navy (right) uses a spectroscope to identify elements in the Sun.

restrial elements was abolished once and for all.

Huggins, for one, was elated by these discoveries and couldn't help but speculate on what this implied. In 1864 he and his collaborator, W. Allen Miller, wrote that

> it is remarkable that the elements most widely diffused through the host of stars are some of those most closely connected with the constitution of the living organisms of our globe. . . . that at least the brighter stars are, like our sun, upholding and energizing centres of systems of worlds adapted to be the abode of living beings.

It wasn't the first time that scholars speculated about life on extrasolar planets, but the new astrochemical data now made it more than a theoretical fantasy.

A century later, some researchers became even more ambitious. In 1955, physicist Charles H. Townes, who would later win a Nobel Prize for the invention of the maser (the microwave precursor to the laser) was invited to address an international symposium on radio astronomy in England. His topic: the possibility of detecting celestial substances, other than simple elements, via their radio emissions. Townes, a renowned molecular spectroscopist, suggested that elements were likely linking up and forming actual molecules out in space—molecules that emitted intense radio waves. Among the candidates he named were carbon monoxide (CO, the dangerous stuff of car exhaust), ammonia (NH_3), water (H_2O), and the hydroxyl radical (OH, the oxygen-hydrogen combination that distinguishes all alcohols).

The response to Townes's talk was tepid, however. Most astronomers at the time were convinced that such molecules were too rare to seek out. Optical astronomers had already recognized a few molecular species in space, such as the methylidyne and cyanogen radicals (CH and CN), but theorists were sure that, once formed, such molecules quickly got destroyed by ultraviolet and cosmic rays. Why devote precious radio telescope time to tracking scarce specimens, which everyone assumed were unimportant to astronomical processes? One of Townes's colleagues cautioned him that such a search would be "hopeless."

Fortunately, a few MIT radio astronomers didn't heed those warnings and looked anyway. In 1963 they found OH screaming out at a frequency of 1,667 megahertz in the supernova remnant Cassiopeia A. Five years later, Townes himself, along with coworkers at the University of California at Berkeley, recorded the radio cries of both ammonia and water molecules in the galactic center.

A race quickly ensued to snare the next new cosmic molecules. By 1973 nearly 30 were identified; the total today is more than 150—from acetone and hydrogen cyanide to formaldehyde, methane, and nitrous oxide (laughing gas). Astronomers handed out cases of liquor to settle bets once ethyl alcohol was detected in 1974. It's been estimated that 10^{22} (that's one followed by twenty-two zeros) fifths, at 200 proof, reside in the gas cloud where the alcohol was first detected. Of course, the molecules are spread out so thinly in space that you'd have to distill a volume as big as the planet Jupiter to get one stiff drink.

These assorted molecules barely register as pollutants in our galaxy. Only one molecule of ammonia, for example, forms for every 30 million molecules of hydrogen. Yet scarce as these molecules are, their strong radio signals allow astronomers to better map both the Milky Way and the universe.

Hydrogen peroxide, the hair-bleaching agent, was uncovered just last summer (who knew the cosmos secretly desired to be a blonde?). Using a submillimeter-radio-wave telescope perched on a high desert plateau in the Chilean Andes, an international team of astronomers found traces of the chemical in a dense cloud of gas and dust near the star Rho Ophiuchi, some 400 light-years distant. Hydrogen peroxide is formed when two hydrogen atoms link up with two oxygen atoms (H_2O_2). Both elements are critical for life as we know it. Moreover, take just one oxygen atom out of hydrogen peroxide and you get water (H_2O). So, further study of hydrogen peroxide's chemistry out in deep space may help astronomers better understand the formation of water in the universe.

Molecule by molecule—from water to glycine—astronomers are proving that the foundations for life on Earth may have been put into place before our planet even formed nearly 5 billion years ago.

MARCIA BARTUSIAK is executive director of the MIT Graduate Program in Science Writing. Her latest book, The Day We Found the Universe *(Pantheon), won the History of Science Society's Davis Prize in 2010 for best history-of-science book for a general audience.*