ASTRONOMY

The Keck Scopes Out the Legacy of the Big Bang

In the pages of *Mademoiselle* and *Cosmo*, there's an eternal debate about whether bigger really is better. Some say yes, some no. But when it comes to telescopes, there's no contest: Bigger is better. That fact was underscored again last week when a group of astronomers reported using the 10-meter Keck telescope on Mauna Kea, the largest single-mirror telescope in the world, to take the temperature of the early universe and measure a scarce form of hydrogen left behind by the Big Bang. The evidence—subtle spectral fingerprints in the light from a quasar, a brilliant object at the far edge of the universe—is beyond the ken of smaller telescopes. Faint as they are, however, these clues are enough to bear out astronomers' overall picture of the universe's birth and evolution, while raising disturbing questions about the composition of today's universe.

What Antoinette Songaila and Lennox Cowie of the University of Hawaii, along with Craig Hogan and Martin Rugers of the University of Washington, found in the quasar's light are the "shadows" cast by a cloud of primordial gas, which lay just in front of the quasar when the universe was perhaps an eighth of its present age. Written in those shadows is evidence that the universe has steadily expanded and cooled as it aged, as predicted by the standard Big Bang theory. The result, reported in this week's *Nature*, is gratifying to most astronomers. But another implication of the quasar's spectrum, that the early universe may have had an unexpectedly high abundance of deuterium, or heavy hydrogen, isn't sitting so comfortably.

"The fact that so many very good people have tried to do this for so many years," says University of Chicago astronomer Donald York, "establishes it as an absolutely fundamental measurement." But if it's right—not all astronomers think so—ordinary matter, made up of protons and neutrons, is an even scarcer component of the universe than astronomers had thought, and even more of the universe's mass must consist of some kind of exotic, unseen matter.

The reason so much hangs on the universe's deuterium content is that the element—hydrogen with an added neutron—could only have been forged in the hot, neutron-rich environment instants after the Big Bang. Based on their understanding of the primordial element-forming processes, physicists can come up with rough estimates of the fraction of primordial hydrogen that would have been produced as deuterium. But they can't calculate the absolute amount; that depends on the total density of ordinary matter in the primordial element furnace. The greater the density, the lower the furnace's yield of deuterium, and vice versa. As a result, deuterium measurements provide a means of "weighing" the total amount of ordinary matter in the cosmos.

And that's one reason so many researchers have tried to make those measurements. Until now, however, astronomers have been limited by their instruments to measuring deuterium within the solar system and the local interstellar medium, where it is probably much scarcer than it was in the early universe. That's because the nuclear furnaces within stars destroy deuterium by turning it into isotopes of helium. Astronomers have had to extrapolate back to the primordial abundance from these local measurements. But by measuring deuterium in a distant gas cloud, says University of Chicago cosmologist David Schramm, Songaila and her colleagues "are getting the deuterium abundance in such an early epoch that it has not been messed up or depleted."

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The amount of deuterium implied by the gas cloud's spectrum, about two atoms for every 10,000 atoms of ordinary hydrogen, is within the range of values allowed by the standard Big Bang. So is the second result from the spectrum, an upper limit to the temperature of the cosmic background radiation—the afterglow of the Big Bang—during the era of the gas cloud. Certain excited states of carbon, visible in the spectrum as "fine structure" lines, could only have been stimulated by photons of the background radiation; by measuring the lines' intensity, Songaila and her colleagues were able to infer an upper limit for the temperature of the radiation. That temperature should have been higher then than it is now—and so it was, by about the expected amount.

But the results aren't all reassuring. Gary Steigman of Ohio State University, for example, is now preparing a paper arguing that the Songaila group's deuterium measurement doesn't square with what is known about the present-day universe. Since the deuterium abundance in our cosmic neighborhood is about four times lower than the value measured for the early universe, says Steigman, most of the primordial deuterium must have been burned into helium-3 inside stars. "And if you destroy a lot of deuterium, you wind up producing a lot of helium-3, and the present helium-3 abundance should be very high." Recent observations of helium-3 in the solar system and the interstellar medium imply, he says, that it's not.

The Hawaii group itself raises the possibility that their measurement might have been contaminated by another gas cloud along the same line of sight. If this putative second cloud were moving at just the right speed, the absorption lines produced by ordinary hydrogen within it would have matched those of deuterium in the more distant cloud, making that cloud appear to be richer in the isotope than it is. But Schramm thinks that the uncertainties in the helium-3 measurements are too large to cast serious doubt on the Hawaii result. "Unfortunately, helium-3 is hard to measure," he explains. Furthermore, as Alfred Vidal-Madjar of the Institute of Astrophysics in Paris points out, nearby measurements of another form of helium, helium-4, do seem to agree with the high deuterium abundance Songaila and her colleagues are claiming.

Steigman and other theorists have another reason for discomfort with the result, however: It would have significant implications for the make-up of today's universe. Chief among them, he says, is that "the contribution of baryons [ordinary matter] to the density of the universe would be a factor of three lower than we thought." In that case, nearly all of the unseen "dark matter" thought to account for most of the universe would have to consist of exotic particles whose nature physicists can only guess at. Many cosmologists had already resigned themselves to the presence of at least some exotic matter in the universe. But the new result could imply that even the halos of dark matter believed to surround galaxies—often assumed to consist of ordinary matter such as dead stars—consist of these mystery particles, says Schramm.

The only way to be sure, however, is to search for signs of deuterium in the spectra of other quasars. As Schramm explains, "If they actually detected the true primordial value, they have got to see that same number in many other lines of sight." Songaila and her colleagues agree wholeheartedly. In fact, next week, they'll be heading back to their telescope, where bigger is assuredly better.

–Ray Jayawardhana

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