NEWS

The Quest for Population III

Astronomers may soon see traces of the first stars in the universe—and they're likely to be whoppers

Most creation stories begin with the first rays of light. As astronomers tell the tale, the brilliance of the big bang faded to a black murk for at least 100 million years. Gravity pulled gas into clumps, but nothing shone. Then, somewhere, the nuclear fires of the first star cast light into the void. That event marked the end of what Cambridge University astronomer Martin Rees calls the cosmic "dark ages," and it started a cycle of star birth and death that transformed a simple broth of gas into the complex stew of elements we see today.

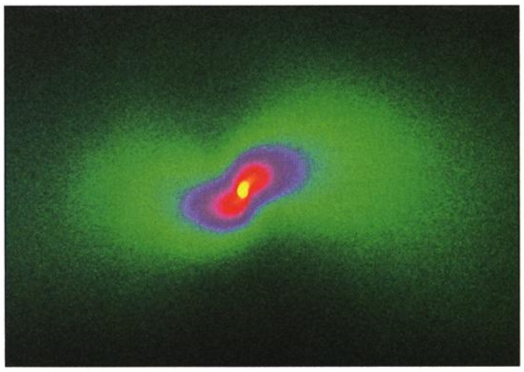
The primordial ancestors of today's stars have long since vanished from our sector of space-time. However, recent research promises a glimpse of the first stars. Simulations of collapsing clouds in a starless universe predict that gigantic stars formed, each containing about 100 times more gas than our sun. Most of those titans lived fast and died so explosively that new telescopes should be able to see them as supernovae or gamma ray bursts at the margins of the visible universe. By spewing a unique blend of chemical ingredients into space, the first stars probably spawned a second generation of lighter objects—some of which may linger today.

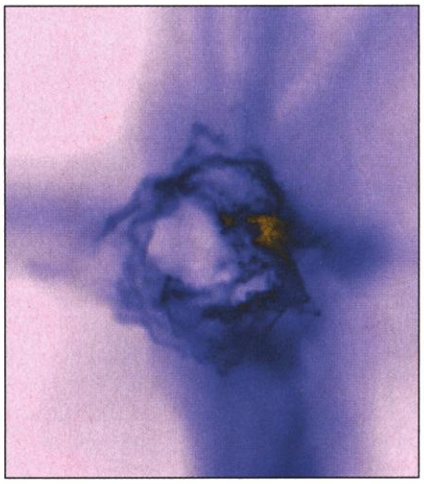
Moreover, astronomers are devising ways to explore the neighborhoods in which the first stars blasted through life. Searchlight beacons from the most distant quasars have lit the edges of a key region within which ultraviolet (UV) light from the earliest stars ionized the universe. Other astronomers are using the intense gravity of galaxy clusters as lenses to magnify tiny parts of the universe, exposing shreds of light from the first infant galaxies in the throes of formation.

Within a decade, the Next Generation Space Telescope (NGST) should see those dim objects clearly. But for now, astronomers are thrilled to open the curtain on the cosmic stage for a mere glimpse of the first act. "Mankind has always been interested in how the first light was produced," says astronomer Abraham Loeb of the Harvard-Smithsonian Center for Astrophysics (CfA) in Cambridge, Massachusetts. "Now we have the opportunity to address that question with scientific tools for the first time."

Doomed giants

Loeb and his colleagues are pursuing "Population III" stars, which contain only the pristine mixture of hydrogen, helium, and a dash of lithium created in the big bang. The name extends the stellar categories invented 50 years ago by German astronomer Walter Baade: Population I, stars such as our sun with ample elements heavier than hydrogen and helium, and Population II, rarer stars with few heavy elements. These "metal-poor" stars, as astronomers call them, are ancient, but they still contain a smattering of elements such as carbon, oxygen, silicon, and iron from primordial stars that preceded them.





Big star, big boom. Simulations of the first star point to a seed dozens of times more massive than our sun (*above*) and an explosive death that disrupts its entire halo of gas (*right*).

CREDITS: (TOP TO BOTTOM) VOLKER BROMM *ET AL.*; TOM ABEL *ET AL.*

Astronomers have never seen a pure Population III star, despite years of combing our Milky Way galaxy. The best they have managed is to find a few "extreme Population II" stars, in which iron is only 1/10,000 as abundant as in our sun. To make the leap to Population III, some researchers are using silicon—not in stars, but in the chips of supercomputers.

The setting in which the first structures formed is surprisingly tractable to model, says astrophysicist Michael Norman of the University of California (UC), San Diego. "It struck me as curious that the whole field of structure formation was focused on clusters and superclusters today, which are horribly complex," Norman says. "From a physics standpoint, things are simpler as you go back to the early universe."

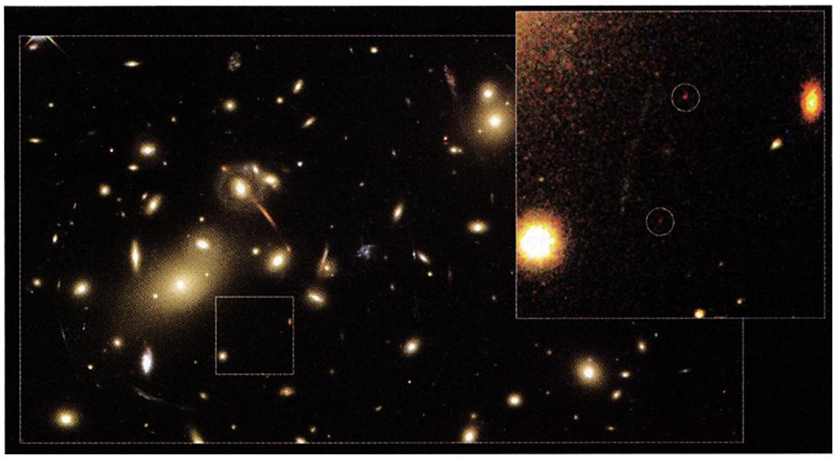
Specifically, hydrogen and helium are easier to understand than the dozens of elements that drive star formation now. No other stars roiled the pot, and magnetic fields were negligible. Using a modeling method called "adaptive mesh refinement," Norman's team tracks a cloud of gas in a simulated cube of space 400,000 light-years across as it collapses into a ball just 100 times as large as the sun. "If you think of the universe as the size of Earth, our calculation can resolve a single red blood cell," says astrophysicist Tom Abel of Pennsylvania State University, University Park.

On page 93 of this issue, Abel, Norman, and astrophysicist Greg Bryan of Oxford University report their latest results. Contrary to some expectations, the collapsing gas cloud does not split into myriad small stars. Rather, a single giant star forms, sucking in gas at a startling rate. The likely final mass of the star is between 50 and 300 times the mass of our sun, Abel says.

Another set of simulations by astrophysicist Volker Bromm of CfA and by Paolo Coppi and Richard Larson of Yale University in New Haven, Connecticut, yields a similarly hefty first generation. The reason, Bromm says, is that in order to contract into stars, gas clouds need to cool dramatically, but molecular hydrogen in the early universe can't cool the gas below a relatively balmy 150 kelvin. Dust and heavier molecules, such as carbon monoxide, radiate heat so efficiently that modern star-forming clouds plunge to 10 K or so. That leads to tighter knots of gas and smaller stars.

The giants of the early cosmos were raging bonfires of fusion, consuming their fuel in a few million years. Their deaths weren't ordinary, either. Calculations by astrophysicists Alexander Heger and Stan Woosley of UC Santa Cruz and their colleagues predict that primordial stars between 140 and 260 times the mass of our sun exploded as extraordinarily brilliant supernovae. Their flares of light, stretched into infrared wavelengths by the expansion of the universe, should be spotted by NGST—and perhaps by the Space Infrared Telescope Facility, due for launch in July 2002.

A subset of those first detonations may have triggered gamma ray bursts, the most energetic events in the cosmos. "We should be able to see gamma ray bursts no matter how distant they are," says astronomer James Rhoads of the Space Telescope Science Institute in Baltimore, Maryland. One reason is that bursts and their fireball "afterglows" are brighter than supernovae across most of the spectrum, Rhoads says, and gamma rays zing through gas and dust. A second reason stems from the time-dilating tricks of relativity. Primordial stars recede from Earth so quickly that when they explode, their bursts seem to last much longer than if the stars were nearby. That makes it easier to catch them in the act.



Arc lights. The powerful gravity in galaxy cluster Abell 2218 magnifies and distorts remote objects—including a faint star-forming blob 13 billion light-years away (*inset*).

CREDIT: ESA/NASA (RICHARD ELLIS/CALTECH AND JEAN-PAUL KNEIB/OBSERVATOIRE MIDI-PYRÉNÉES)

Ultradistant bursts may be detected soon. A planned gamma ray satellite called Swift, to fly by the end of 2003, should detect about one gamma ray burst per day. Swift will alert telescopes on the ground to look for afterglows. Analysis will reveal how far away the bursts are, providing clues about when and how often the earliest stars blew up.

Although the prospect of spotting remote explosions is tantalizing, other Population III enthusiasts are looking closer to home. Extreme Population II stars in the extended halo of our galaxy may be just one step removed from the firstborn stars. "We believe we see the chemical history of the first generation written into low-mass second-generation stars that are still burning," says astronomer Timothy Beers of Michigan State University in East Lansing. The few Milky Way stars that have 1/10,000 of the sun's allotment of heavy elements may record "single pollution events": a spray of metal-laden gas from the death of just one giant star.

Heger and Woosley's team predicts that such a chemical fingerprint should be rich in silicon and barren of metals heavier than zinc. Unusual neutron physics within the first stars also should expel a pronounced "odd-even pattern" of elements, producing 10 to 100 times more mass of the even-numbered elements in the periodic table than of their odd-numbered neighbors. Spectral studies of ancient stars in the Milky Way haven't turned up anything so distinctive, Beers notes, but the search continues.

Distant windows

As the first stars forged heavy elements, they also scorched their surroundings with fierce UV light. This radiation stripped electrons from the hydrogen atoms that had formed 300,000 years after the big bang from the universe's initial hot bath of protons and electrons. By "reionizing" the universe, the earliest stars forever changed how light travels through intergalactic space, because neutral hydrogen atoms absorb the UV light from young stars.

Reionization didn't happen all at once, says astronomer S. George Djorgovski of the California Institute of Technology (Caltech) in Pasadena. Rather, patchy islands of ionized hydrogen formed around the first stars within a sea of neutral hydrogen. "It's a phase transition, like the bubbles in boiling water," Djorgovski says. "They grow and eventually overlap, and the whole thing turns into steam. That's the response of the gas filling the universe to the light from the first sources."

Four months ago, a team claimed that the most distant quasar yet known lies just beyond the final fringes of reionization. The quasar, detected by the Sloan Digital Sky Survey, arose about 1 billion years after the big bang. Neutral hydrogen between us and the quasar completely absorbed some of the quasar's light, according to astronomer Robert Becker of UC Davis and Lawrence Livermore National Laboratory in California and his colleagues. The amount of light that made it through, however, implies that most of the neutral hydrogen must lie still farther away, in a region within which the universe's first reionized bubbles are hidden. "None of us believe we are seeing all the way back to a fully neutral universe," Becker acknowledges.

Total reionization required a lot of UV radiation, most likely from small assemblages of stars rather than single giant stars. However, those first stellar groupings may have been so small—like the globular clusters that swarm around the Milky Way today—that even deep exposures by the Hubble Space Telescope can't detect them. Fortunately, nature provides another means: gravitational lensing.

First predicted by Albert Einstein as part of his theory of general relativity, gravitational lensing occurs when something massive bends the light of a more distant object into a smear or a multiple image. The biggest clusters of galaxies in the cosmos are adept at this optical wizardry. One of them, called Abell 2218, is laced with ghostly arcs from the warped images of more distant galaxies. A survey of the most highly magnified slices of sky behind Abell 2218 recently exposed two tiny red jewels.

A team led by Caltech astronomer Richard Ellis, director of the Palomar Observatory, found the red patches with the 10-meter Keck Telescope in Hawaii. Spectra confirmed that they were images of the same small system of stars, split and magnified about 30 times by gravitational lensing. The type of light emitted by the stars suggests that the system is hot and nearly newborn. "We believe we're seeing stars that were less than 2 million years old" when they emitted their light, Ellis says, at a time less than a billion years after the big bang.

Ellis doesn't claim that the stars in his vigorous but minuscule system are the long-sought Population III. "We can't yet rule out that it arose from a second-generation event," he says. "We're dying to know whether there's any evidence of an underlying older stellar population that we can't see." The team has received more time with Hubble to stare at the patches for signs of such parent stars.

Even if Population III stars elude these various techniques, astronomers feel confident that NGST will succeed. "NGST is the optimum instrument to view the first objects directly," says CfA's Loeb. "It's perfectly tuned to the right wavelengths to observe the early universe." Those infrared signals—faint wafts of heat straggling across 14 billion light-years of space—may illuminate the dark ages once and for all.

–ROBERT IRION