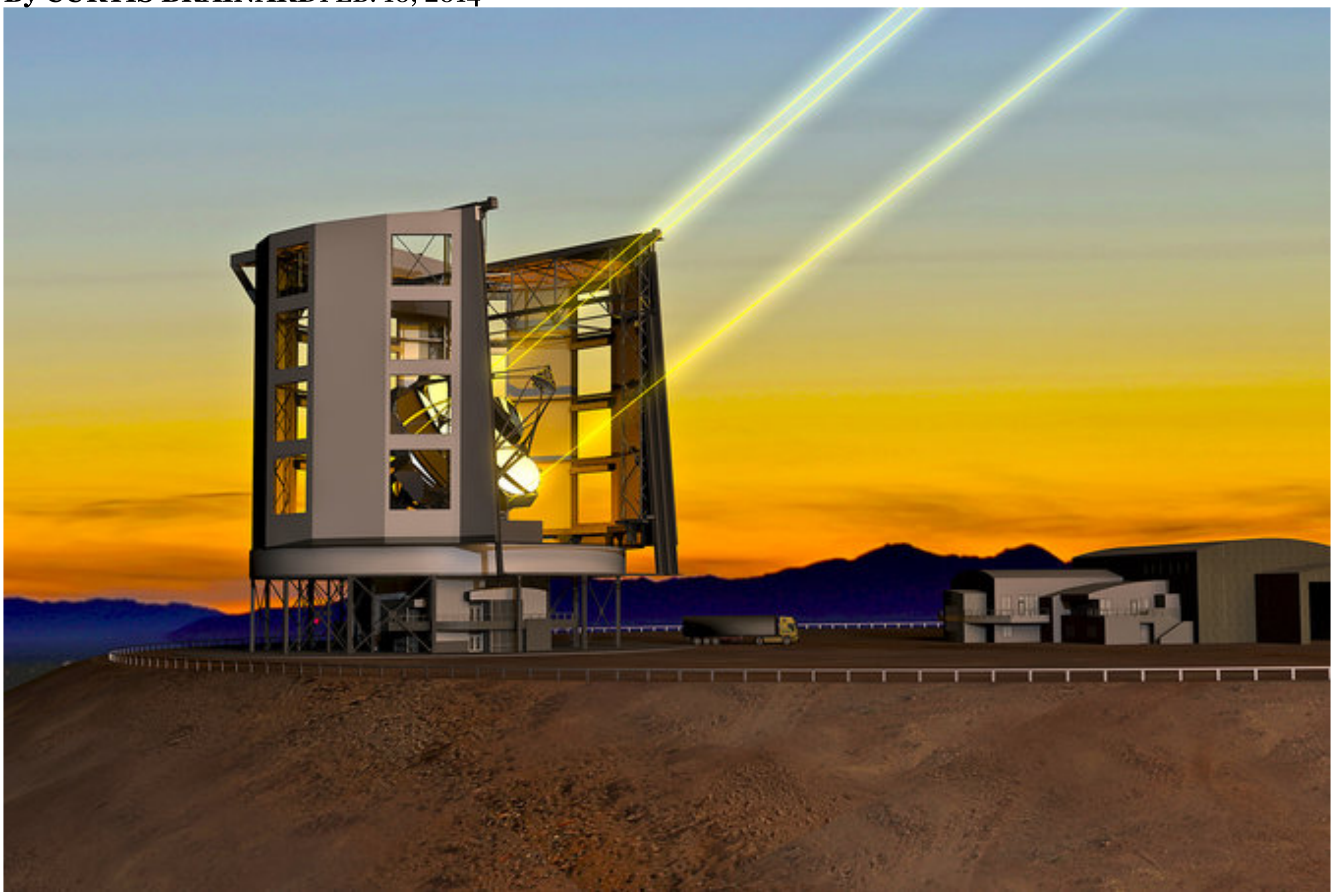
SPACE & COSMOS

The Archaeology of the Stars

By **CURTIS BRAINARD**FEB. 10, 2014



A drawing of the Giant Magellan Telescope, which will be set up in the Atacama Desert in Chile and allow an even deeper look into the early universe. Todd Mason/Giant Magellan Telescope Organization

Four years ago, Anna Frebel, a young astronomer at the Massachusetts Institute of Technology, found an ancient star in a neighboring galaxy whose chemical composition proved nearly identical to some unusual stars on the outskirts of our own galaxy, which are older than the Milky Way itself.

It was a striking discovery, suggesting that the relatively young Milky Way is growing by conquest — "cannibalizing" nearby older dwarf galaxies. And it underscored the importance of a new way of learning how the universe evolved from the Big Bang to the modern cosmos.

Traditionally, astronomers study the early universe by looking back in time — peering deeper and deeper into space for vestiges of light from billions of years ago. But in the last decade, Dr. Frebel and others have used powerful telescopes and high-resolution spectroscopes to study the chemical composition of very old stars closer to home, in the Milky Way's halo, producing a wealth of information about the creation of elements and the formation of the first stars and galaxies.


Anna Frebel, of M.I.T., uses powerful telescopes and high-resolution spectroscopes to study stars' chemical composition.

These astronomers are like Egyptologists combing the desert for relics of bygone civilizations, and call themselves stellar archaeologists. Their work relies on the fact that the rare, primordial stars they are looking for have very few atoms heavier than hydrogen and helium, the gases from which they came together. By contrast, our sun and other relatively young stars are rich in other elements, which astronomers collectively refer to as metals.

Astronomers believe that some of the old stars formed from the chemically enriched dust left over from the explosive deaths of the very first generation of stars, and their atmospheres contain important information about their forebears, like DNA passed from parent to offspring.

The hunt for these scarce antiquities goes back to the early 1950s, when scientists recognized that not all stars have the same metal-rich chemical composition as the sun. "At the time, they didn't know what to do with the metal-poor stars," Dr. Frebel, 33, said.

But astronomers have since established what she called "a framework for the chemical evolution of the universe."

Building Blocks

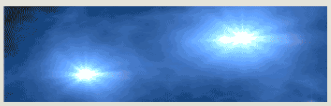
The first stars were made up entirely of hydrogen, helium and negligible traces of lithium. With no heavy elements to cool the gas clouds, they grew massive, rapidly burned through their fuel and exploded in supernovas.

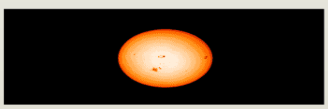
During various burning stages of those first stars' evolution, before and after they exploded, their intense heat fused the hydrogen and helium atoms into heavier elements — the first metals — which in turn enabled the formation of long-lived, low-mass stars.

Some of those early second- and third-generation stars eventually made their way to our corner of the universe, where they long remained unnoticed by astronomers among a sea of even younger stars. Most of the stars we see in the sky are relatively rich in metals like iron and are known as Population I stars because they were once thought to be the only type existing.

Generations of Stars

Astronomers are searching for rare, very old stars that contain hints about the chemical evolution of the universe.





POPULATION III STARS

The first stars formed from primordial clouds of hydrogen and helium, hundreds of millions of years after the Big Bang.

The heavier elements of the periodic table, called “metals” by astronomers, did not yet exist, except for traces of lithium.

Nuclear fusion inside the stars created the elements through iron, and even heavier elements were created when the massive, short-lived stars exploded in supernovas.

Cast into space, the new metals began the chemical enrichment of the universe.

An artist’s impression of
early star formation

POPULATION II STARS

Metal-poor stars formed from the scattered remains of the first stars, and contain small amounts of metals.

Astronomers detect elements in distant stars by measuring the amount of starlight received at different wavelengths. The resulting spectrum is often used to measure the relative abundance of iron compared with hydrogen.

HE 1327-2326, a star near the tail of the constellation Hydra, is one of the most iron-poor stars yet found, with an abundance of iron about 1/250,000 that of the Sun.

HE 1327-2326

POPULATION I STARS

Metal-rich stars like the sun have been enriched by many previous generations of stars, and have higher percentages of metals.
For example, the sun is about 98.6 percent hydrogen and helium, and has a much higher proportion of iron than a metal-poor star like HE 1327-2326.
Stars in the halo of the Milky Way tend to have lower metal content than younger stars in the galactic center. Dark patches in the image above are clouds of gas and dust.

That changed in 1951, when the astronomers Joseph W. Chamberlain and Lawrence H. Aller found the first two Population II stars, with about one three-hundredth the amount of iron as our sun. Three decades later, in 1984, two astronomers at Mount Stromlo Observatory in Australia, John Norris and Mike Bessell, chanced upon a star with just one ten-thousandth the iron abundance of the sun.

Iron content closely corresponds to what astronomers call metallicity, which is expressed on a logarithmic scale: Minus 2.0 is one-hundredth the iron abundance of the sun, –3.0 is one-thousandth, and so on. The newly discovered star was –4.0.

It was a serendipitous find, according to Dr. Norris, who along with Dr. Bessell would become a Ph.D. adviser to Dr. Frebel.

"It was called CD -38° 245, if you like star names," Dr. Norris said, "and we knew that we'd gone down to something very pristine, but we also suspected that it was not the end of the story. So we worked hard here and elsewhere to find more metal-poor stars than that, but it wasn't for almost another 20 years that someone would."

A survey of the southern sky in the 1990s produced a trove of potential metal-poor stars. In 2002, Norbert Christlieb at the University of Hamburg in Germany announced that one of them, 36,000 light-years away in the constellation Phoenix, in the Milky Way's galactic halo, had a metallicity of –5.2 — a "relic from the dawn of time," as the journal Nature put it.

Shortly after, Dr. Christlieb met Dr. Frebel, then a young undergraduate who was taking time off from her physics studies in Germany to do research at Mount Stromlo, part of Australian National University.

"I immediately recognized that she was a very talented student," Dr. Christlieb said. "We had this idea to explore the brighter stars" in the 1990s survey, "and I asked if she'd be interested in developing methods to find interesting objects. She agreed, and of course her work was very successful."

Dr. Frebel stayed in Australia to continue her doctoral work, and before her degree was even in hand she had found a star with a metallicity of –5.4.

Archaeologist to the Stars

Anna Frebel uses light emitted from stars to find the oldest among them.

Until last week, that star was the most iron-poor astronomers had found. Then, on Sunday, astronomers announced a record. In a paper in Nature, Dr. Frebel and a group of colleagues, including Stefan Keller of Australian National University, the lead author, described a star in the Milky Way constellation Hydrus with a metallicity of less than –7.1 (only an upper limit could be determined).

The star, SMSS 0313-6708, is presumably very old, perhaps the oldest yet identified. The astronomers who found it estimate that it formed over 13 billion years ago. But they cannot say exactly how old it is. One of the few ways to get a precise age for a star is to find one with radioactive elements like uranium and thorium, whose half-lives are known and can be used — like carbon 14 on earth — to date an object with certainty.

Only about 5 percent of stars are thought to have such a chemical signature. Still, Dr. Frebel described one such star in 2007: a red giant 7,500 light years from Earth that at 13.2 billion years old is one of the two oldest known stars in the universe that have actually been dated. “We would hope for a consistent relationship” between metallicity and age, she said, “but the problem is that the uncertainties are so large and the samples so few that it’s hard to map out.”

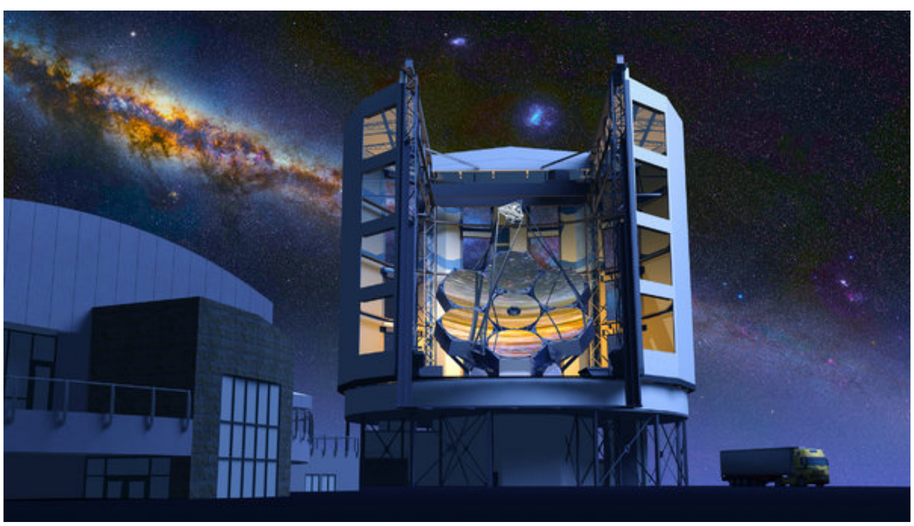
By now, astronomers have found six stars with less than one ten-thousandth of the sun’s iron abundance, –4, and those are the ones that interest them the most.

“The signatures in the stars we’ve discovered since 2000 are quite different from what we find in other, what you might call ‘normal’ metal-poor stars,” Dr. Norris said. He and others believe that they could have come only from the supernova of a single first-generation star.

Astronomers, Dr. Frebel said, “are finding stars that are over 13 billion years old — what we think are plausible second-generation stars.”

She continued: “So now we’re trying to decipher their chemical composition in order to answer questions like ‘How massive were the first stars? How many were there? How and where were the elements produced? How did they explode? And how did the first low-mass stars form?’ ”

Seeking Cosmic Relics



Giant Magellan Telescope

The Giant Magellan Telescope, when built, will have a resolving power 10 times greater than the Hubble Space Telescope.

After Dr. Frebel locates a metal-poor star that she wants to analyze in detail, she heads for Las Campanas Observatory, atop a remote peak in the Atacama Desert in Chile. There she stays awake all night with one of the twin Magellan telescopes trained on her target for hours at a time.

A high-resolution spectrograph stretches the photons of starlight across the visible wavelength, telling her how many atoms of each element the star contains. Back home, other scientists run computer simulations to see how the data from her observations correspond with different models of the universe's evolution.

The Methuselahs of the cosmos have divulged some tantalizing hints of how it all happened. Their chemical compositions suggest, for instance, that the first supernovas may not have carried as much explosive energy as astronomers once believed.

In turn, this implies that the first stars may not have been as massive as thought, and that some of the first supernovas "sort of failed," as Dr. Frebel put it — with much of the star's material falling back into a black hole rather being ejected into space.

Another critical observation is that five of the six known stars with metallicities below –4.0 have unusually high levels of carbon relative to iron. Dr. Frebel said that could be a sign that the element played an important role from the outset, instigating the cooling of interstellar gas that allowed the first low-mass stars to form.

On the other hand, one of the stars is not similarly enriched with carbon — suggesting that dust molecules could also have acted as a cooling mechanism.

The discovery announced on Sunday supports these conclusions. But six stars are not enough to be sure of anything, so astronomers are counting on a variety of new sky surveys, including Australian National University's SkyMapper project, which is already producing large new catalogs of stars for study.

"It is very exciting that SkyMapper has now shown to be capable of finding these rare, ancient stars," Dr. Frebel said. "It is already a great achievement for this new survey and promises many great returns in the near future."

When it comes to metal-poor stars, how low can you go? Such remnants of the early universe are uncommon and hard to find, but stellar archaeology is a young field, and new artifacts will undoubtedly come to light.

Indeed, stellar archaeologists hope they might find a long-lived low-mass star from the first generation.

At the moment these "primes" exist only in theory. But they could be out there, astronomers say, lying in some dark corner of the universe like an undiscovered pharaoh in his tomb, waiting to tell us about life along the banks of the Nile thousands of years before the Common Era.

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