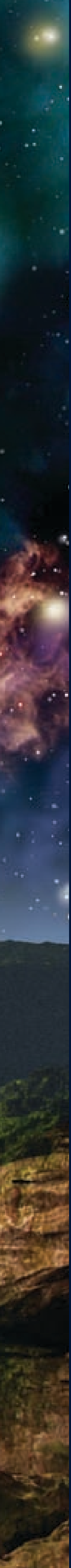
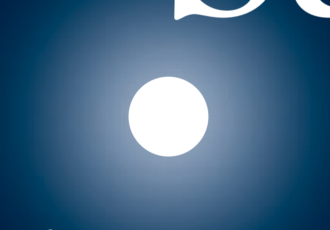


The Long-Lost Siblings of the Sun



The sun was born in a family of stars. What became of them?

By Simon F. Portegies Zwart

People have often sought solitude in the starry night sky, and it is an appropriate place for that. The night is dark because, in cosmic terms, our sun and its family of planets are very lonely. Neighboring stars are so far away that they look like mere specks of light, and more distant stars blur together into a feeble glow. Our fastest space probes will take tens of thousands of years to cross the distance to the nearest star. Space isolates us like an ocean around a tiny island.

Yet not all stars are so secluded. About one in 10 belongs to a cluster, a swarm of hundreds to tens of thousands of stars with a diameter of a few light-years. In fact, most stars are born in such groups, which generally disperse over billions of years, their stars blending in with the rest of the galaxy. What about our sun? Might it, too, have come into existence in a star cluster? If so, our location in the galaxy was not always so desolate. It only became so as the cluster dispersed in due time.

HAD YOU BEEN ALIVE at the dawn of the solar system, the night sky would have been bright enough to read by. A thousand or so stars formed within a few light-years from the same interstellar cloud the sun did.

RON MILLER

KEY CONCEPTS

- The sun is a solitary star, and astronomers have traditionally assumed it formed as such. Yet most stars are born in clusters, and scraps of evidence from meteorites and from the arrangement of comets suggest that our sun was no exception.
- Its birth cluster could have contained 1,500 to 3,500 stars within a diameter of 10 light-years—a big, unhappy family whose larger members bullied the small fry and which broke up not long after our solar system came into being.
- Although the sun's siblings have long since dispersed across the galaxy, observatories such as the European GAIA satellite will be able to look for them. Their properties might fill in the gaps of the solar system's deep history. *—The Editors*

[THE AUTHOR]

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A growing body of evidence suggests just that. Although conventional wisdom once held that the sun was an only child, many astronomers now think it was one of 1,000 or so siblings all born at nearly the same time. Had we been around at the dawn of the solar system, space would not have seemed nearly so empty. The night sky would have been filled with bright stars, several at least as bright as the full moon. Some would have been visible even by day. Looking up would have hurt our eyes.

The cluster into which the sun was probably born is now long gone. I have pieced together the available data and made an educated guess as to what it might have looked like. From these inferred properties, I have calculated the possible trajectories of former cluster members through the galaxy to figure out where they might have ended up. Although they have scattered and mixed in with millions of unrelated stars, they should be identifiable with the European Space Agency's Global Astrometric Interferometer for Astrophysics (GAIA) satellite, scheduled for launch in 2011. Their orbits and sunlike compositions should give them away. Reuniting with our long-lost stellar siblings should enable astronomers to reconstruct the conditions under which a shapeless cloud of gas and dust gave rise to our solar system.

Memories of Our Birth

The most compelling evidence that the sun has close siblings emerged in 2003, when Shogo Tachibana, now at the University of Tokyo, and Gary R. Huss, now at the University of Hawaii at Manoa, analyzed two primitive meteorites that are thought to be almost pristine leftovers of solar system formation. They detected nickel 60, the product of the radioactive decay of iron 60, in chemical compounds where, by rights, iron should be found. It seems a game of chemical bait and switch took place in the meteorite: the compounds originally formed from iron, the iron metamorphosed into nickel, and the nickel was locked in place, forever an interloper.

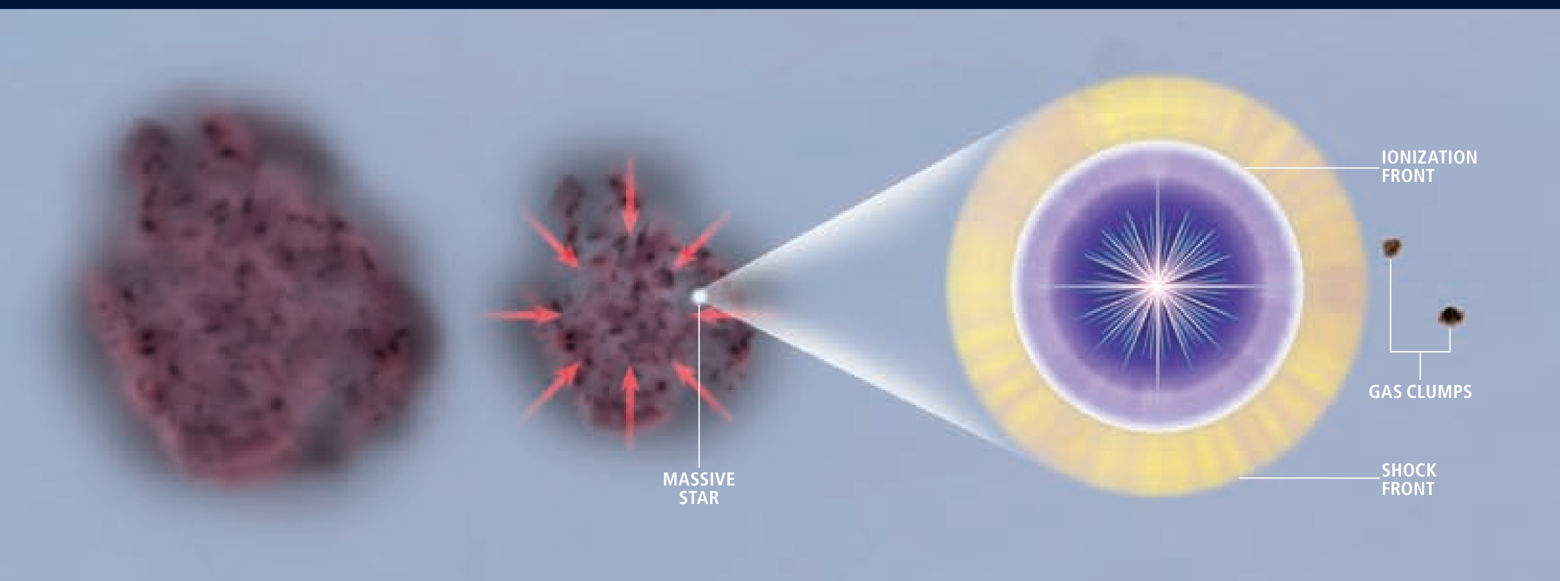
The iron 60 had to be synthesized, injected into the solar system and incorporated into meteorites within its radioactive half-life, which, according to a new estimate published this past August, is 2.6 million years. That is a cosmic eyeblink. Therefore, the iron had to come from very nearby—and the likeliest source is a supernova

COURTESY OF MEREI PORTEGIES ZWART-MASSEE (*Portegies Zwart*); DON DIXON (*illustrations*)

[SOLAR PREHISTORY]

THE BIRTH OF THE SUN'S CLUSTER

Based on observations of star clusters and the inferred properties of the cluster into which the sun was born, J. Jeff Hester and Steven J. Desch of Arizona State University and their colleagues have reconstructed the events leading up to the formation of the sun.



A giant cloud of molecular gas accumulates and begins to collapse under its own weight.

One or more massive stars form in the densest regions of the cloud.

Each massive star pours out ultraviolet radiation, ionizing the surrounding gas and driving out a shock front. The shock expands at a few kilometers per second.

STAR CLUSTER **R136, located in a region known as the Tarantula Nebula, is similar to (but much denser than) the cluster into which the sun was born.**

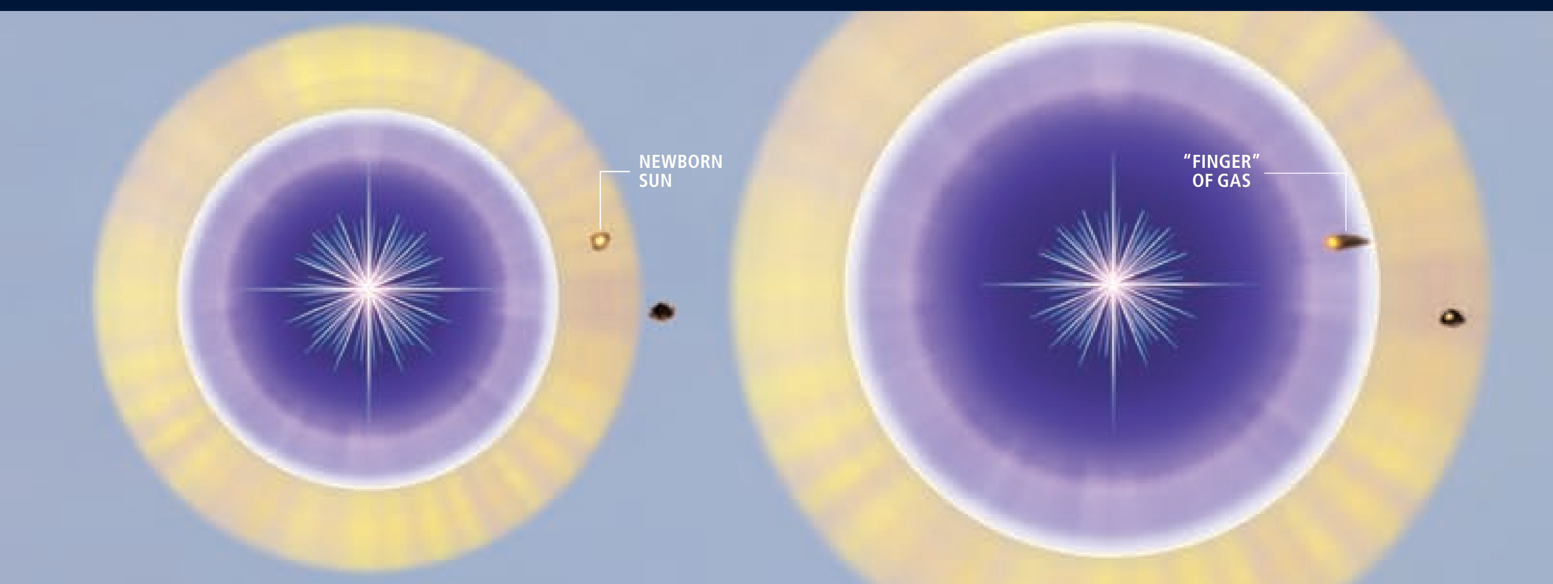
NOLAN WALBORN *Space Telescope Science Institute/NASA*, JESÚS MAÍZ APELLÁNIZ *Institute of Astronomy of Andalucía* AND RODOLFO BARBÁ *University of La Serena*

explosion. Based on this and other isotopic measurements, Leslie Looney of the University of Illinois and his co-workers argued in 2006 that a supernova went off within a distance of five light-years when the sun was scarcely 1.8 million years old. The supernova might have been as close as 0.07 light-year. (The new half-life estimate will change these values, but not substantially.)

If the sun had been as secluded as it is today, the location and timing of the supernova would be quite a coincidence. Was a massive star simply passing by when it decided to blow up? No other supernova has ever gone off at such close range; if it had, it would probably have wiped out life on Earth. A much more plausible explanation is that the newborn sun and the exploding star were fellow members of a cluster. With stars packed so tightly together, a close supernova would not have been so improbable.

The Starry Clusters Bright

The idea that the sun originated in a star cluster is at odds with the classical view of clusters that is still common in textbooks. Astronomers have traditionally classified clusters into two types: so-called galactic, or open, clusters and globular clusters. The former are young, sparsely populated and located primarily in or near the plane of our galaxy. The prototypical example is Praesepe, also known as the Beehive cluster or as M44. It was one of the first objects at which Galileo pointed his telescope 400 years ago, in



Within a few million years the shock front reaches nearby gas clumps and compresses them. They collapse and form stars, including our sun.

Some 100,000 years later the ionization front hits the newborn sun and starts to boil off loose circumsolar gas. A gaseous finger may connect the system to the molecular cloud.

NOT AN ONLY CHILD

Several lines of evidence suggest that the sun was born in a cluster:

- Ancient meteorites contain the decay products of short-lived radionuclides such as iron 60 and aluminum 26. The source of the isotopes (probably a supernova) must have been very nearby, indicating that the early sun was not alone.
- The sun's levels of heavy elements are higher than its location in the galaxy would otherwise indicate—suggesting that it was topped up with debris from a nearby supernova.
- Uranus and Neptune are much smaller than Jupiter and Saturn. One reason might be that the radiation of a nearby star boiled off their outer layers. Planets closer to the sun avoided this fate because residual interplanetary gas shielded them.

1609. What looked like a splotch of light revealed itself as an array of stars—up to 350 of them, all born about 700 million years ago.

In contrast, globular clusters are very old, densely populated and located all around the galaxy, not just in a plane. The first was discovered in 1746 by Italian astronomer Giovanni Maraldi and is now known as M15. It contains about a million stars with an age of about 12 billion years.

The trouble is that neither category fits the sun. Its advanced age of 4.6 billion years suggests it should have been born in a globular cluster, yet its location in the galactic disk points to a galactic cluster. In the past two decades, however, we have realized that not all clusters fall neatly into one of these two classical types [see "The Unexpected Youth of Globular Clusters," by Stephen E. Zepf and Keith M. Ashman; Scientific American, October 2003].

What changed our minds was the star cluster R136, which is located in one of the Milky Way's small satellite galaxies, the Large Magellanic Cloud. First spotted in 1960, R136 was initially thought to be a single, giant star 2,000 times as massive as the sun and 100 million times as bright. But in 1985 Gerd Weigelt and Gerhard Baier, both then at the University of Erlangen-Nürnberg in Germany, used new high-resolution imaging techniques to show that R136 is actually a cluster of about 10,000 stars a few million years old. It is as dense as a globular but as young as a galactic cluster. With characteristics of both types, R136 was the missing link between them. Since then, observers have found several clusters like R136 in our galaxy. Other galaxies such as the Antennae contain hundreds if not thousands of them.

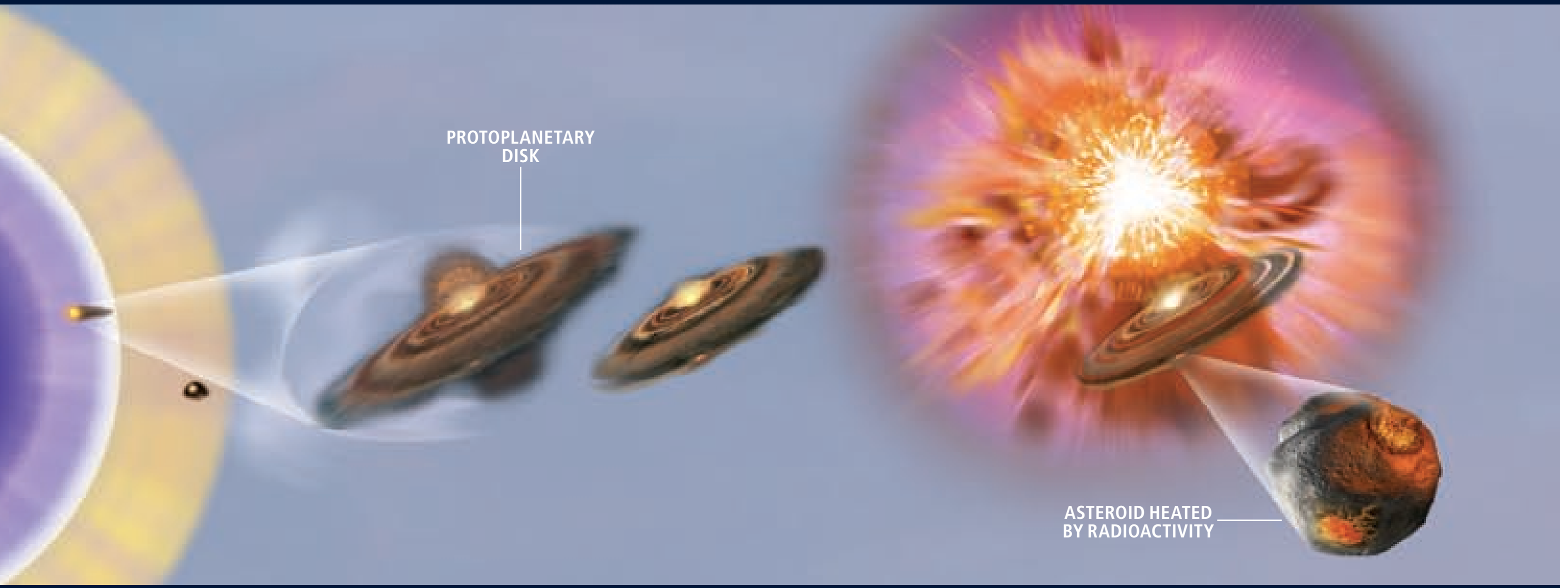
The discovery that stars continue to form in clusters so dense they could be mistaken for a single star was astonishing. It led to considerable consternation among theorists. On the one hand, we were relieved, because we had not been able to explain R136 as a single superstar. On the other hand, we had to reconsider everything we thought we knew about star clusters. We now think that all stars, including the sun, are born in tight clusters such as R136. A cluster forms out of a single interstellar gas cloud and, over time, evolves into either a galactic or globular cluster depending on its mass and environment.

DON DIXON

[TIMELINE CONTINUED]

THE DEATH OF THE SUN'S CLUSTER

The sun's birth cluster eventually disperses, but not before helping to shape the solar system. Radiation from other stars acts like a cookie cutter to set the size of the system; a nearby supernova salts the growing planets with radioactive isotopes; and the gravity of a passing star scrambles comets' orbits.



Within 10,000 years the loose gas boils off entirely. The sun's protoplanetary disk is then directly exposed to ultraviolet radiation.

Over the next 10,000 years or so, this radiation erodes the disk beyond about 50 astronomical units (AU) in radius.

About two million years later the massive star blows up and rains debris onto the solar system, including freshly created radioisotopes. These are incorporated into planetary building blocks and power early geologic activity.

Dreams from Our Stellar Fathers

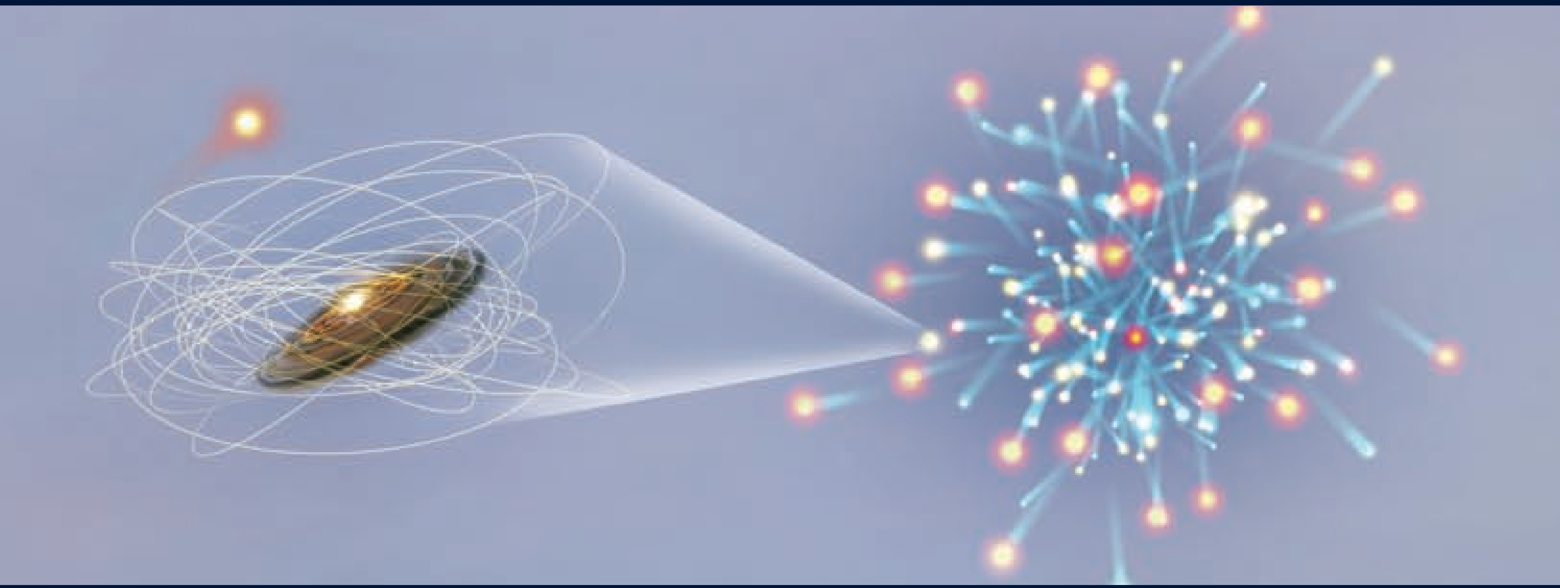
The members of a cluster span a range of masses, with a few heavy stars and a multitude of lightweight ones. The least massive, with a tenth the mass of the sun, are the most common, and for every factor of 10 increase in mass, the abundance of stars drops by about a factor of 20.

Thus, for each star of 15 to 25 solar masses—the size of the one that went supernova near the newborn sun—a cluster contains some 1,500 lesser stars. This number sets the minimum mass of the sun's birth cluster. The maximum mass is set by the fact that the larger a cluster is, the longer it takes for massive stars to settle toward the center, where they have the greatest likelihood of affecting their smaller brethren. Based on my simulations, the cluster probably contained fewer than about 3,500 stars.

A star of 15 to 25 solar masses lives for six million to 12 million years before blowing up, so it must have formed about this long before the sun did. In other clusters, such as the famous Trapezium cluster in the Orion Nebula, astronomers have found that massive stars are usually the first to form, with sunlike stars arising several million years later.

A cluster of the inferred mass was too flimsy to evolve into a globular cluster. Instead it dispersed after 100 million to 200 million years. The massive stars at its center shed gas in stellar winds (similar to but much more intense than the solar wind) and eventually exploded, reducing the density of material in the cluster and thereby weakening its gravitational field. Consequently, the cluster expanded and might have fallen apart. Even if it survived this early outgassing, interactions among stars and the tidal forces exerted by the rest of the galaxy drove its slow dissolution.

Before the cluster disintegrated, stars were so densely packed that one could easily have passed through the solar system. A stellar close encounter would have pulled planets, comets and asteroids from their original circular, planar orbits into highly elliptical and inclined orbits. Many comets beyond a distance of 50 astronomical units (AU), past the orbit of Pluto, have highly skewed orbits. The internal dynamics of the solar system seem incapable of accounting for these peculiar orbits; the bodies are beyond the gravitational influence even of Jupiter. The most likely explanation is that they were stirred



Sometime within the next 100 million years or so, another star in the cluster passes a few thousand AU from the sun, stirring up comets on the outskirts of the solar system and setting them on inclined orbits.

Its gravity weakened by the self-destruction of its most massive members, the cluster disperses in about 100 million to 200 million years. The sun and other cluster members slowly drift apart.

What is puzzling is that the sun's orbit, traced back in time, suggests our solar system was born farther out in the galaxy than it is now.

up by a star passing 1,000 AU away. The planets, though, have very regular orbits, indicating that no stellar intruder ever came within 100 AU of the sun.

From these facts, I have estimated the dimensions of the cluster. For another star in the cluster to pass 1,000 AU away with reasonable probability over the cluster lifetime, the cluster had to be less then 10 light-years in diameter. Conversely, for a star not to come within 100 AU, the cluster had to be greater than three light-years in diameter. In short, the sun's birth cluster looked like R136 but much less dense, so that stars were far enough apart not to interfere with planet formation.

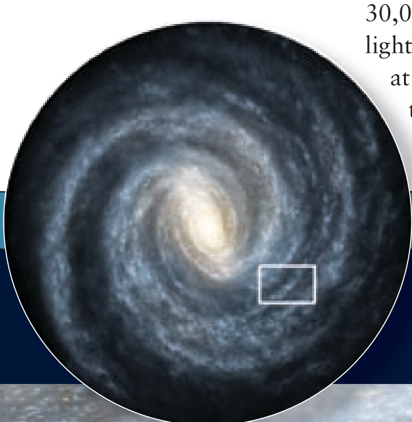
Solar Genealogy

Theorists can go further and ask where exactly in the galaxy the birth cluster was located. The solar system revolves around the galactic center in an almost circular orbit, more or less in the disk. At the moment, we are located about 30,000 light-years from the center and about 15 light-years above the plane of the disk, orbiting at a speed of 234 kilometers per second. At this rate, the sun has done 27 circuits since its formation. Its orbit is not a closed loop but a somewhat more complicated shape determined by the gravitational field of the galaxy, which astronomers infer from the motion of stars and interstellar gas clouds.

Assuming, provisionally, that the gravitational field has not changed over the past 4.6 billion years, I have projected the orbit backward in time and deduced that the sun was born 33,000 light-years from the center and 200 light-years above the galactic plane. What makes this position puzzling is that the outer reaches of the galaxy are poorer in heavy elements than the inner parts. The most distant regions may lack enough material to make planets, let alone life [see "Refuges for Life in a Hostile Universe," by Guillermo Gonzalez, Donald Brownlee and Peter D. Ward; Scientific American, October 2001]. Although the sun's putative birthplace is not quite so impoverished, it is still poorer in heavy elements than the sun is. Based purely on the sun's heavy-element composition, astronomers would have expected it to form 9,000 light-years closer to the center.

Maybe the supernova that seeded meteorites with iron 60 also enriched the sun with heavy

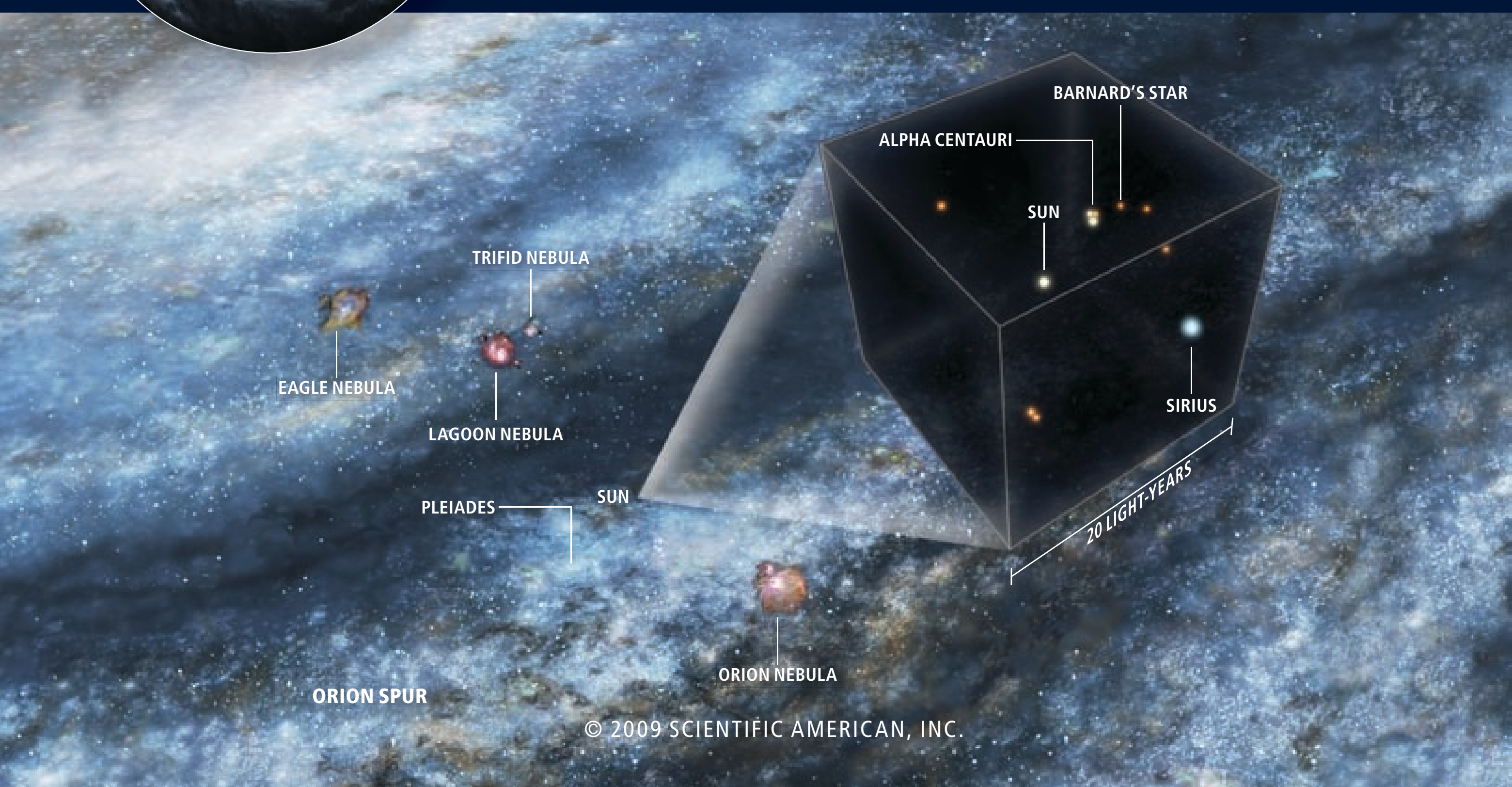
DON DIXON



[GEOGRAPHY OF THE GALAXY]

MEET THE NEIGHBORS

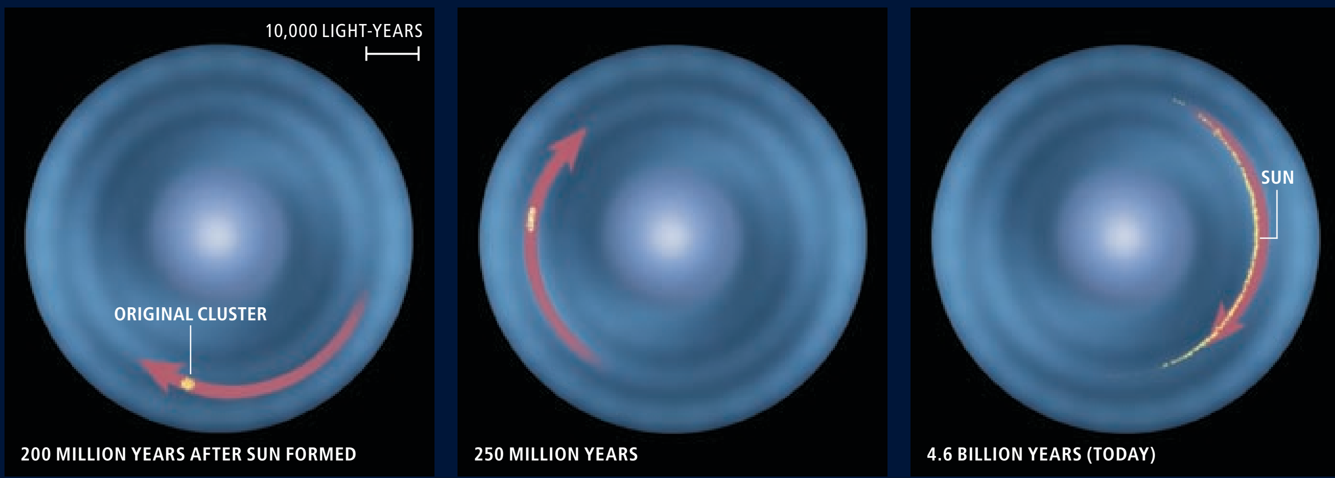
The sun currently lies about 30,000 light-years from the center of the Milky Way galaxy. Astronomers know of only 11 other stars within 10 light-years of the sun. Before the sun's cluster dispersed, the same volume held more than 1,000 stars.



[CLUSTER DISPERSAL]

FAMILY BREAKUP

By tracking the likely orbits of the sun's siblings as they dispersed, theorists can estimate where they ended up, so that observers can search for them. The discovery of even one would help reconstruct the origin of the solar system.



The sun and its siblings move apart at a few kilometers per second, while continuing to orbit the galaxy's center at more than 200 kilometers per second.

After doing a fourth of an orbit around the galactic center, the stars have spread out only 100 or so light-years.

After making 27 full orbits, the stars form a stream tens of thousands of light-years long. A few percent of them still lie within 300 light-years of the sun.

DON DIXON

elements. Or maybe my orbital calculation went astray because the gravitational field of the galaxy has changed or because the sun's orbital path was diverted slightly by the gravity of nearby stars or gas clouds. In that case, the sun was born closer to the center than I estimated, and its composition is not so anomalous.

The sun's ex-family members, too, should be orbiting around the galactic center at more than 200 kilometers per second. Yet their relative velocity, which is determined by their mutual gravitational forces in the original cluster, is only a few kilometers per second. Like clumps of cars on a highway, they stick together even though they are no longer bound to one another gravitationally. The original swarm has spread into an arc only very gradually. After 27 orbits, it should stretch about halfway around the galaxy.

My calculations suggest that about 50 of the sun's brothers and sisters should still be within 300 light-years of our current location and that about 400 stars are within 3,000 light-years. Depending on the stars' original relative velocity and the timing of their departure from the cluster, the sun either follows in their orbital footsteps or they in ours.

The best place to look for them is in the plane of the galaxy in the direction the solar system is moving or in exactly the opposite direction. One of my students is now looking for them in a catalogue of stars assembled by ESA's Hipparcos satellite in the early 1990s [see "The Star Mapper," by Philip Morrison; Scientific American, February 1998]. But Hipparcos was probably not precise enough to make a positive identification. For that, we will need the GAIA spacecraft. It has a pair of telescopes that will measure the full three-dimensional position and velocity of some one billion stars over five years, creating an essentially complete census of stars within several thousand light-years of the sun. In the data, we can look for stars that lie nearly along the sun's past and future orbital path. Their composition should look like the sun's, because the same supernova that polluted the early solar system will have done the same to other stars in the cluster.

Identifying even a single sibling of the sun will provide some much needed information about the very early days of the solar system, a period otherwise lost to history. Theorists will be able to compute the birthplace of the sun with greater certainty and determine, for example, whether the gravitational field of the galaxy has changed substantially or not. Not least, solar siblings will be excellent places to look for habitable planets. Although we seem very alone in the galaxy, it was not always that way. Many of the sun's seeming idiosyncrasies—not least that it nurtures life—might make sense in the context of its family. ■

MORE TO EXPLORE

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Radioactive Probes of the Supernova-Contaminated Solar Nebula: Evidence That the Sun Was Born in a Cluster. Leslie W. Looney, John J. Tobin and Brian D. Fields in *Astrophysical Journal,* Vol. 652, No. 2, pages 1755–1762; December 1, 2006. Available online at **arxiv.org/abs/astro-ph/0608411**

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