Gaia's Mission to the Milky Way

About 200 billion stars shine in the Milky Way, most hidden from our view by interstellar dust. The European Space Agency's Gaia mission should obtain distances and other data about all stars as faint as magnitude 20.

In the next decade, a unique spacecraft will start pinning down the positions and distances of more than a billion stars.

RESULTS FROM HIPPARCOS, the European Space Agency satellite launched in 1989 to measure star positions, have upgraded practically every branch of modern astronomy beyond the solar system. Hipparcos achieved its pervasive influence by doing a fundamental, seemingly simple task: measuring distances to stars accurately. This is crucial information that almost everything else in astronomy builds upon, one way or another, even out to the edges of the observable universe.

All that reckoning will soon be redone, and done far better. A much more advanced satellite named Gaia, also built by the European Space Agency, should provide far more precise data on the positions and motions of not just 118,000 stars as Hipparcos did, but a billion of them.

Gaia, now under construction, is scheduled to launch in 2011. It will spend five years measuring — and remeasuring, again and again — the positions of all stars to 20th magnitude much more accurately than Hipparcos measured stars to magnitude 10. The processing of Gaia's observations will be so vast and complex that it's expected to take several additional years, even with the faster computers expected to be available by then. The results should become available around 2020.

The measurement of star positions is called *astrometry*, and astronomers are more impatient for this kind of data than you might think. We still don't have a good map of even our own sector of our galaxy. Gaia will provide that map, in complete, 3-D detail — with exquisite findings about stars' individual distances, movements relative to the galaxy's spiral arms, brightnesses (including variability), and colors. Other instruments on Gaia will record spectra and find radial velocities for a subset of the stars observed, things Hipparcos didn't do. The spacecraft's observations should reveal startling novelties about countless faint stars we've never paid much attention to.


Michael Perryman

S&T: ROGER W. SINNOTT

Michael Perryman, who was project scientist for Hipparcos and went on to spearhead Gaia through its first seven years of development, hopes the craft will also characterize the masses and orbits of more than 10,000 planets of other stars. It will be especially suited to detecting the gravitational presence of giant planets in large orbits like Jupiter's or Saturn's. Such planets move so slowly that they've remained practically "invisible" to today's exoplanet search teams, who've been forced to rely mainly on the Doppler effect to detect a parent star's gravitational wobble spectroscopically.

Mission astronomers likewise hope to identify 50,000 new brown dwarfs (failed stars) and 20,000 novae — not to mention about 250,000 asteroids (of which 90% will already be known) in our own solar system. But more basically, Gaia will turn many branches of astronomy and astrophysics into truly precision sciences for the first time.

Twenty Thousand Stars at a Glance

The current plan is to loft Gaia on a Soyuz rocket, in cooperation with the Russian Space Agency, from ESA's spaceport in French Guiana. After launch, the 2-ton satellite will travel for one month to the L_2 Lagrangian point of the Earth-Sun system, which lies 1.5 million km away (four times as far as the Moon) in the direction opposite the Sun.

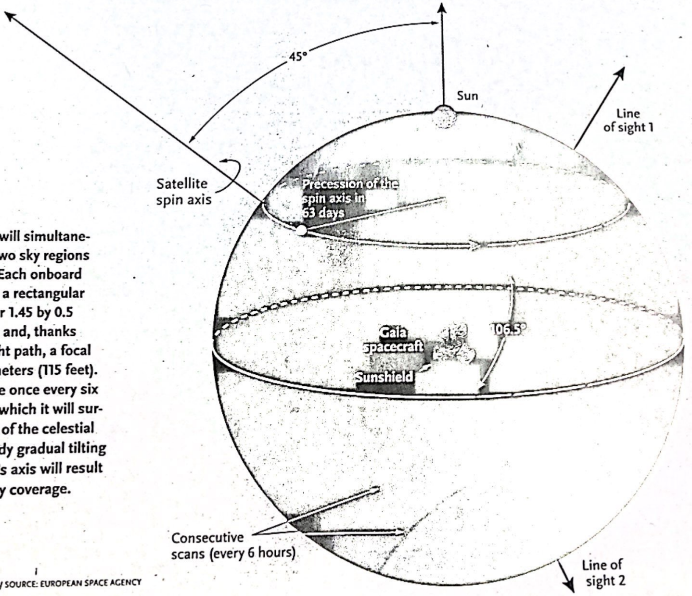
Around this point of relative gravitational equilibrium, Gaia will settle into a leisurely orbit that oscillates around the L_2 point, similar to a Lissajous tracing on an oscilloscope screen. In this way Gaia can avoid ever dipping into Earth's shadow, something that caused cooling and heating problems for Hipparcos in the early 1990s. Another advantage of the distant L_2 point is that Earth blocks much less of the sky — just ½° — than if the craft were orbiting Earth. (The joint US-European James Webb Space Telescope, scheduled to replace Hubble around 2013, is destined for this same faraway location.)

Once on station, Gaia will start mapping stars. At any moment, some 20,000 stars will fall on its CCD array. Two rectangular main mirrors, directed to fields 106.5° apart, will scan thin bands around the sky every six hours. On average, any single star will be observed and measured about 70 times during the five-year mission.

During its shorter mission in 1989–93, Hipparcos measured positions to an accuracy of about 0.001 arcsecond for 118,000 stars fairly close to the Sun (see the January issue, page 31). Gaia's measurements will not only be more precise but will include 10,000 times as many stars. Astronomers will thus get much better information about a more representative sampling of the Milky Way's roughly 200 billion stars.

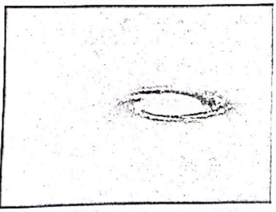
The Sky's the Limit

Expectations for Gaia run high. As just one example, Pavel Kroupa (Bonn University) wants to see if open star clusters are evolving the way his computer models predict. Most stars form in clusters embedded in giant molecular clouds; the Orion Nebula (M42) is one. But the



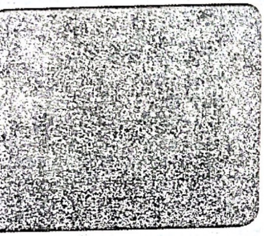
Gaia's optics will simultaneously image two sky regions 106.5° apart. Each onboard telescope has a rectangular primary mirror 1.45 by 0.5 meters in size and, thanks to a folded light path, a focal length of 35 meters (115 feet). Gaia will rotate once every six hours, during which it will survey a thin ring of the celestial sphere. A steady gradual tilting of the satellite's axis will result in complete sky coverage.

S&T: GREGG DINDERMAN / SOURCE: EUROPEAN SPACE AGENCY


SOURCE: EUROPEAN SPACE AGENCY

Hipparcos obtained accurate distances to nearly all stars within several hundred light-years of the Sun (tiny inner circle). Gaia will probe with similar accuracy all the way to the galactic center (26,000 light-years) and beyond.

Orion Nebula's star cluster isn't even a million years old, a toddler on the cosmic time scale. In all of Kroupa's model calculations, as soon as a molecular cloud's searingly hot and massive *O* stars ignite, the gas around them heats up and is expelled.



Without the mass of this gas helping hold it together, the cluster loses stability and many of its stars drift away. With Gaia, Kroupa hopes to map the motions of such flyaway stars. He expects small galaxies to be especially disturbed by processes like these.

Other astronomers are eager to explore how our Milky Way Galaxy first formed and how it developed into its present state. If we could map our galaxy properly, we'd see that it actually has two superposed disks: one that's at least 4,000 light-years thick, and a brighter one less than 1,000 thick. Both measure about 100,000 light-years across. All the youngest stars are located in the "thin disk," in which our Sun resides as well. The galaxy's characteristic spiral arms are zones of higher star density within the thin disk.

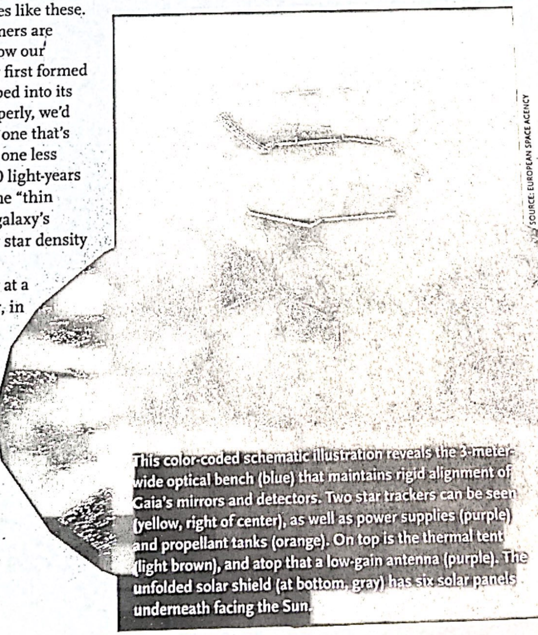
The Sun circles around the galaxy's center at a distance of 26,000 light-years. Near the center, in the direction of the constellation Sagittarius, great numbers of old stars form the *galactic bulge.* Encompassing all these structures is the Milky Way's huge, spherical *halo* — a sparse scattering of occasional loose stars and globular clusters. The halo stars are the galaxy's oldest.

Although we seem to have the Milky Way's landscape pretty well explored, "its history is far from known," says Ulrich Bastian (Heidelberg University), a Hipparcos veteran who will be deeply involved in the Gaia data analysis.

According to the widely accepted Cold Dark Matter theory of how the largest cosmic structures formed after the Big Bang (*S&T:* January 2002, page 16), gas and dark matter started congregating in small units only, blobs with roughly the masses of globular clusters. "First mini-galaxies formed, with only a few million stars," Bastian explains. "Later on larger galaxies came together, featuring 10 million to 100 million stars. But even those were still dwarf galaxies."

Computer models show that it wasn't until much later that material accumulated into large enough clumps to form star systems the size of our galaxy. If this is true, then where have all the dwarf galaxies gone? Hundreds of them should be circling the Milky Way (*S&T:* October 2007, page 20). But we know only a handful, including the Magellanic Clouds. One possible explanation is that the Milky Way devoured its dwarfs. That is, after colliding with our home galaxy they were pulled apart by tidal forces and incorporated into it.

In fact Hipparcos, the Sloan Digital Sky Survey, and other surveys find clues to back this hypothesis. When a team led by Amina Helmi (then at Leiden University, Netherlands) examined the Hipparcos data on giant stars near the Sun, 12 of them caught the team's attention. "These 12 showed a high resemblance to each other in

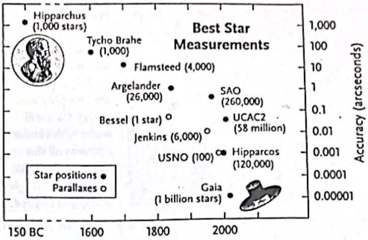

SOURCE: EUROPEAN SPACE AGENCY

This color-coded schematic illustration reveals the 3-meter-wide optical bench (blue) that maintains rigid alignment of Gaia's mirrors and detectors. Two star trackers can be seen (yellow, right of center), as well as power supplies (purple) and propellant tanks (orange). On top is the thermal tent (light brown), and atop that a low-gain antenna (purple). The unfolded solar shield (at bottom, gray) has six solar panels underneath facing the Sun.

their speed and direction of motion," Bastian explains, "whereas the movements of the other stars were random."

These 12 turned out to be part of a much larger stream of stars traveling in parallel. Computer simulations show the stream extending far into the halo and possibly containing millions of stars. "This is the residue of a gigantic collision billions of years ago," Bastian deduces — a dwarf galaxy swallowed up by the Milky Way. Gaia will take a much closer look at up to 100,000 stars in this one halo stream. "Then we will be able to reconstruct the collision," the Heidelberg astronomer expects.

Many other halo streams have been identified. One of them includes the sparse Sagittarius Dwarf Galaxy, which the Milky Way is still devouring. This distant drama is hard for us to observe because it's taking place behind the galactic center from our vantage point. Only a thorough statistical analysis of stellar spectral types and luminosities revealed the brutal truth. Another known stream includes Arcturus (*S&T:* February 2004, page 22). Gaia should find several hundred new halo streams.



SOURCE: EUROPEAN SPACE AGENCY

Ever since the era of Greek astronomer Hipparchus, *astrometry* — the careful measurement of star and planet positions — has been crucial to our grasp of how the cosmos works. With its phenomenal gain in accuracy and reach, Gaia should prove this is truer now than ever.

"Over centuries, astronomy and astrometry were practically identical," comments Perryman. Then the rise of spectroscopy near the end of the 19th century taught us about stars as actual physical bodies rather than mere points of light, and exhaustive star mapping came to be considered old fashioned. But times have changed again. "In the next decade," Perryman predicts, "all branches of astronomy will profit from the astrometry renaissance" — with Gaia in the front line. ✦

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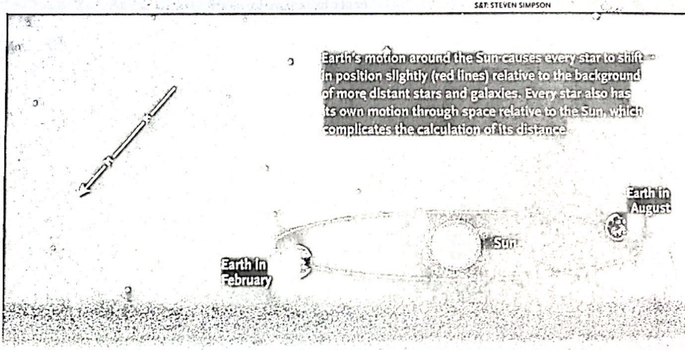
How Parallax Works

S&T: STEVEN SIMPSON



Earth's motion around the Sun causes every star to shift in position slightly (red lines) relative to the background of more distant stars and galaxies. Every star also has its own motion through space relative to the Sun, which complicates the calculation of its distance.

Earth's motion around the Sun causes every star to shift in position slightly — first one way and then, six months later, the other way. The closer the star is to our solar system, the greater this shift. But even in the case of Proxima Centauri, our nearest stellar neighbor, this semiannual shift, or *parallax*, is just 0.772 arcsecond — a deviation that's extremely difficult to measure with an ordinary telescope.

The reciprocal of a star's parallax yields its distance in *parsecs*. That is, a six-month shift of 1 arcsecond corresponds to a distance of 1 parsec (3.26 light-years). So Proxima is 1/0.772, or 1.30, parsecs away. Multiplying by 3.26 converts this to the more familiar value of 4.2 light-years.

Traditionally, astronomers measured the parallaxes of nearby stars relative to the backdrop of more distant reference stars in the same telescopic field. But that raises the question: How distant are *those* stars, and do their own parallax shifts affect the calculation?

Gaia, like Hipparcos before it, will use a completely different approach that was unthinkable before the computer age. It will very accurately measure the spacings of stars about 106.5° apart on the sky, in various combinations, and only at the mission's end solve mathematically for the distances to a billion stars all at the same time. It won't need to "know" which stars are near and which are very remote.

The European Space Agency keeps its website at http://gaia.esa.int/ current with updates on the Gaia mission, including instrumentation, specifications, contractors, costs, and launch schedule.