Hipparcos Charts the Heavens

The catalog of ultraprecise stellar positions mapped by this European satellite could change our understanding of the history of the universe and the lives of stars

On 1 June, a new boxed set of six CDs goes on sale—one more disk than the complete Beethoven symphonies. At a price of $400, it might not seem like an impulse buy, but the world's astronomers are likely to see it as the bargain of the century. Contained on the disks is the most comprehensive star catalog ever created, the fruit of a European Space Agency (ESA) satellite called Hipparcos, which was launched in 1989 but is only now yielding results. Michael Perryman of ESA, who leads the Hipparcos team, describes the new list of star positions and brightnesses as "a giant three-dimensional map of the solar neighborhood."

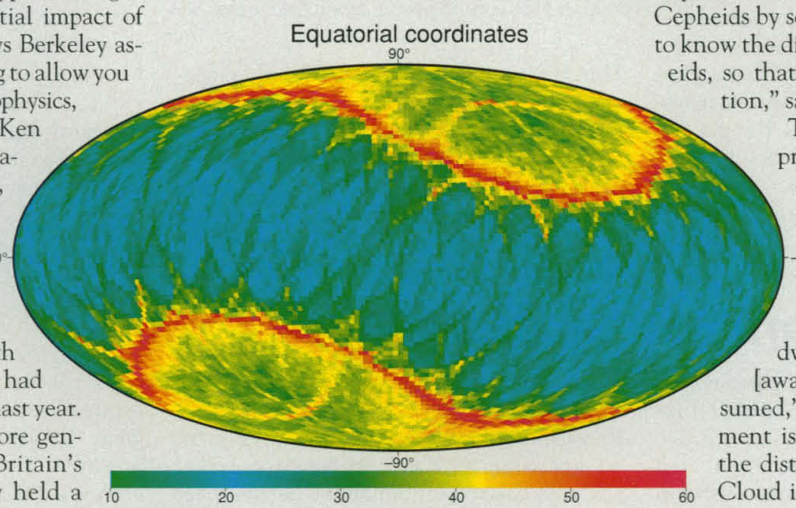
Sharpening up the positions of a few hundred thousand unremarkable stars in our galaxy may sound like a workaday task, but the 100-fold leap in accuracy that the Hipparcos catalog represents is sending ripples throughout astrophysics. "The potential impact of Hipparcos is tremendous," says Berkeley astronomer Ivan King. "It's going to allow you to do a lot of fundamental astrophysics, as well as astrometry," adds Ken Johnston, director of the U.S. Naval Observatory in Washington, D.C. "I believe it is one of the most important projects for modern astrophysics," says Malcolm Longair of Cambridge University.

Investigators involved with the Hipparcos project have had access to its data since August last year. With a few months to go before general release of the catalog, Britain's Royal Astronomical Society held a meeting in London last week to give a taste of the early results. They did not disappoint. Among them is a recalculation of the distances to Cepheid variable stars, one of the standard yardsticks of astronomy, that ups the age of the universe and knocks down the ages of its oldest stars, perhaps easing an apparent contradiction that had puzzled cosmologists. Another headline-grabber for astronomers is a major revision of the Hertzsprung-Russell diagram. A deceptively simple plot of stars' brightness versus their temperature, the HR diagram maps out a kind of evolutionary tree for stars and has become a cornerstone of modern astrophysics. "The new Hertzsprung-Russell diagram is an incredible achievement," says Longair.

All this comes from two star catalogs, the product of 3 years of observing stellar positions and an even longer period of data processing (see sidebar). The more accurate of the two catalogs, called Hipparcos, pinpoints 120,000 stars with an accuracy to 1 milli–arc second, 100 times better than existing star catalogs. "You put a golf ball on the Empire State Building and view it from Europe—that's the kind of measurement accuracy we are talking about," says Perryman, who is based at ESA's technical center in Noordwijk, the Netherlands. The second catalog, called Tycho, contains more than a million stars with a reduced accuracy of between 20 and 30 milli–arc seconds.

Parallax view

What makes these position measurements so important to astronomy is that they enable researchers to calculate stars' distances—and



Scanning eye. Colors on this celestial map indicate the number of scans by Hipparcos's telescope, the key to its high accuracy.

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hence how big and bright they actually are. To calculate distances, astronomers use a method called parallax: If you plot the position of a nearby star and then wait 6 months until the Earth has moved around to the other side of the sun and plot it again, it will have moved slightly against the background of distant stars. "It's just like looking at a scene first with one eye and then the other. Nearby objects shift when you close one eye and open the other," says Michael Feast of the University of Cape Town in South Africa. Nearer stars appear to move more than distant ones, so the size of the shift is an inverse measure of distance.

Of the multitude of stars mapped out by Hipparcos, one group—regular winking stars known as Cepheid variables—is of special interest to Feast and his colleagues. Cepheid variables—the North Star is one—vary in brightness over a regular period that is directly related to the star's intrinsic brightness: The brighter the star, the longer the period.

Hence, astronomers can use Cepheids to measure distances that are well beyond the range of parallax data. If you wanted to measure the distance of another galaxy, you could look for a Cepheid in that galaxy and measure its period. From the period, you could derive its true brightness; by comparing the true brightness with its apparent brightness as seen from Earth, you get the distance. The challenge is to pin down the brightness-period relationship in the first place, which requires measuring the distance to nearby Cepheids by some other method. "You need to know the distances of at least some Cepheids, so that [you] can calibrate the relation," says Feast.

The Hipparcos results have provided the first useful Cepheid parallaxes, which Feast and his colleagues used to recalibrate the Cepheid yardstick. The revised yardstick showed that the Large Magellanic Cloud, a nearby dwarf galaxy, "is 10% farther [away] than was previously assumed," says Feast. This new measurement is vital to astronomers because the distance to the Large Magellanic Cloud is itself a basic yardstick of astronomy. Hubble Space Telescope (HST) scientists, for example, use this value to determine distances to more distant galaxies using Cepheids.

Indeed, the revision may have a profound effect on cosmology. Estimates of the age of the universe from the HST have put it between 9 billion and 13 billion years old, but the oldest stars in the universe, those in the clumps of stars called globular clusters, are thought to be as much as 15 billion years old. Using the new Hipparcos data and revised Cepheid distance scale, Feast's team has derived a new distance scale for globular clusters in the Large Magellanic Cloud and the Andromeda galaxy. The estimated age of the clusters depends on the actual brightness of their stars, which has to be inferred from their apparent brightness and their distance. The distance "turns out to be a good deal greater than previously determined and reduces the age of globular clusters from about 15 billion years to about 11 billion years," says Feast.

At the same time, the revision of the distance to Cepheids in the Magellanic Cloud also leads to a 10% reduction in the value of the Hubble constant—the universe's expansion rate—as measured from more distant Cepheids. A lower expansion rate implies that the universe has had a longer time to slow down since the big bang and hence is older. Feast offers 13 billion years as his best estimate. "An increase of the expansion age and a decrease of the star ages bring things into much better agreement," he argues.

Some astronomers, however, say that it is too early to start redrawing length scales for the entire universe. "My personal feeling is to say wait a while before drawing those sorts of conclusions," says Floor van Leeuwen of Britain's Royal Greenwich Observatory in Cambridge. "The chemical composition of the Magellanic Clouds is somewhat different from what you find in general in galaxies," says van Leeuwen, which could affect the brightness-period relation of the Magellanic Cloud Cepheids. As a result, he says, "direct implementation of these calibrations involves some risks."

To support his argument, van Leeuwen cites Hipparcos data on the Pleiades, the familiar cluster of nearby stars known as the Seven Sisters. Measurements of the cluster "are not at all as expected," says van Leeuwen. Based on the distances measured by Hipparcos, he says, "the stars of the Pleiades cluster appear to be fainter than the average star in the solar neighborhood of the same temperature." The Pleiades were always assumed to be normal stars that fitted well into accepted theory of stellar structure. "The sort of difference we observe there should serve as a warning sign: Don't draw too far-reaching conclusions too quickly."

Starry eyes

Astronomers who study stellar evolution are getting the same warning from Hipparcos, which promises to have a major impact on the Hertzsprung-Russell diagram. This plot of star temperature along the horizontal axis and luminosity marked vertically divides stars into different "species," with cool red supergiants in the upper-right corner and the relatively dim but hot white dwarfs at the lower left. Separating these is the long, diagonal stripe of the "main sequence" stars, running from hot, bright ones at one end to dim, cool ones at the other. Our sun sits roughly in the middle of the main sequence. "[The HR diagram] is one of the keystones of astronomy for doing things like stellar evolution and looking at the life and death of stars," says the Naval Observatory's Johnston. A revised HR diagram based on Hipparcos data will be released along with the catalogs in June.

The precise positions in the Hipparcos catalog are also aiding studies of stellar evolution by enabling astronomers to correlate optical measurements with those made at other wavelengths. Johnston, for example, is merging two different kinds of data to study stars' surface layers, the source of the light that makes stars visible. "I'm interested in overlaying optical images and radio images, and one of the things Hipparcos will do is give me a very good optical reference frame," he says. With optical positions accurate to a milli–arc second and a radio frame good to 100 micro–arc seconds, "I can then overlay my optical image with my radio image and attempt to match these things up," he says.

Patrizia Caraveo and Giovanni Bignami of Italy's Institute of Cosmic Physics in Milan are merging other kinds of data in an effort to understand the pulsar Geminga, the only neutron star known to emit gamma rays but no radio waves. Neither Hipparcos nor HST alone can give a good fix on Geminga's position: Hipparcos is too insensitive to its faint optical signal, and the HST has too small a field of view. But by combining data from both, together with results from ground-based telescopes, Caraveo and Bignami have pinpointed Geminga to 40 milli–arc seconds. "To be able to tell whether the single photons coming from the object are actually in phase with the rotation period, you need to know very accurately the position," says Bignami. And once astronomers can clock how Geminga's spin is slowing down, they may gain insights into its mechanism, he explains.

Dozens of other studies are benefiting from Hipparcos data, including an effort by Martin Barstow of the University of Leicester to determine the absolute sizes of white dwarfs, burned-out stars that are among the oldest objects in the galaxy. Because the size of the dwarfs affects how fast they cool, the measurements are critical for efforts to determine the age of our galaxy from the temperature of these stellar embers. Barstow's best estimate for the galactic age based on white-dwarf temperatures is now between 8 billion and 10 billion years.

Astronomers readily concede that the Hipparcos data proper are short on glamour. But with the long-awaited results starting to flow, Hipparcos scientists hope the project will soon win the recognition it deserves. Like phone books, the Hipparcos catalogs may lack excitement, but they are essential if you want to dial up a whole universe.

–Andrew Watson

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A Mapmaker That Was Nearly Lost

Hipparcos—a tortured acronym for High-Precision Parallax Collecting Satellite—is living up to hopes that it would be the modern successor to Hipparchus, the ancient Greek astronomer who drew up the first accurate star map. But the European Space Agency (ESA) satellite was very nearly stillborn.

After a perfect launch on 8 August 1989, an onboard motor failed to fire, and instead of finding itself in a stable geostationary orbit, Hipparcos wound up in a highly elliptical orbit—arcing up to 36,000 kilometers above Earth, then swooping down to 500 kilometers above the surface. Engineers quickly set about rewriting the satellite's control software and enlisted the help of additional ground stations around the globe to download data. "This was certainly the most significant setback we had to face," says Michael Perryman of ESA, the project leader.

But there were more to come. The orbit plunged the satellite into Earth's radiation belts twice every 10.7-hour orbit, and collisions with particles took a toll on the solar panels. Eventually, in June 1993, Hipparcos fell silent. In that time, however, its wide-field telescope had collected 1000 gigabytes of data on stellar positions.

Because of the way the data had been collected, it had to be processed as a single giant block—not a single star position could be determined until the whole process was finished. "This is the biggest data-handling problem ever undertaken in astronomy," says Perryman, which explains the 3-year wait from the end of the mission to the first release of data last year. "All of that [data] had to be put together into one global astronomical jigsaw from which you extract the positions of each of the stars." –A.W.

ESA

Steady gaze. Hipparcos's 29-centimeter main mirror looks in two directions at once, allowing it to compare stellar movements in different parts of the sky.