Binary stars are all around us, new map of solar neighborhood shows

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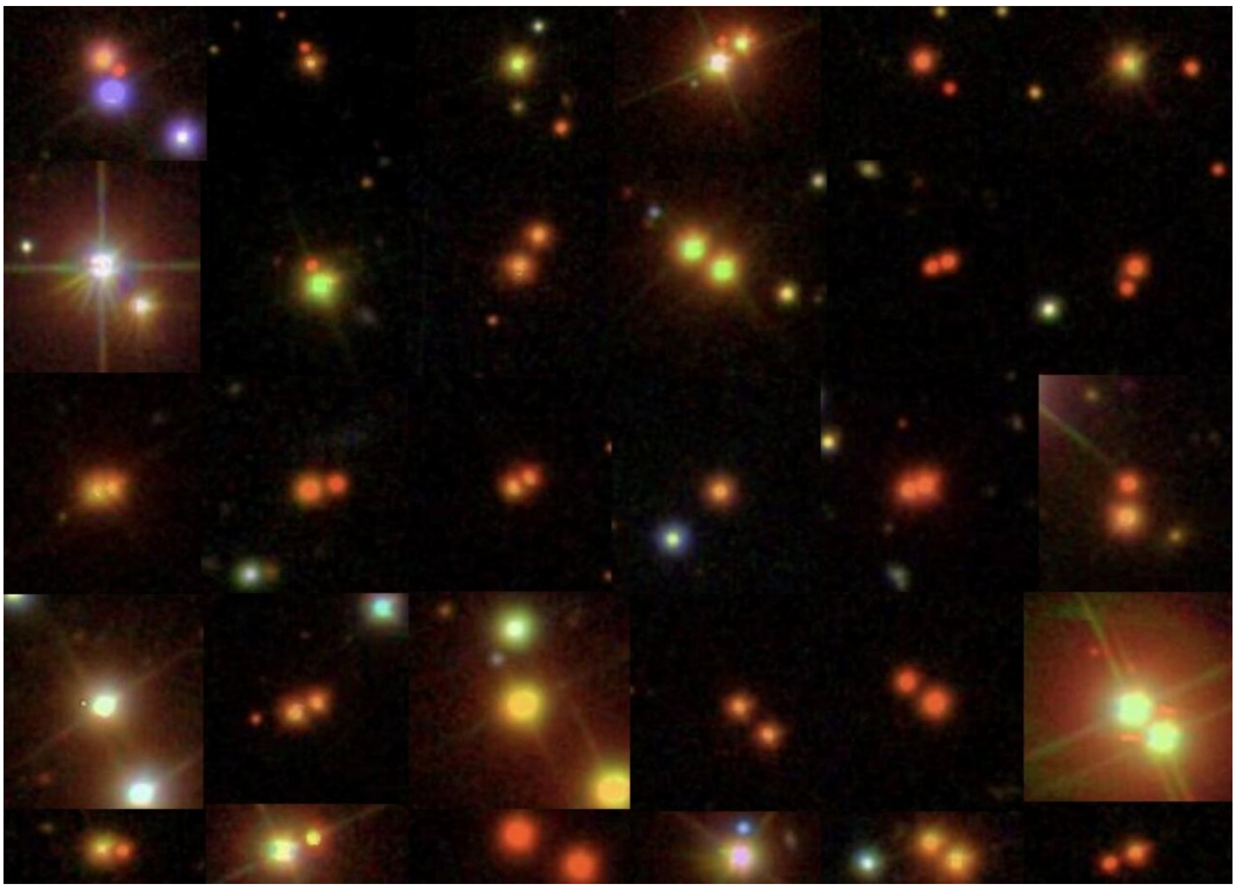


A colorful collage of binary star pairs near Earth, courtesy of the Gaia survey. Credit: ESA/Gaia/DPAC

The latest star data from the Gaia space observatory has for the first time allowed astronomers to generate a massive 3-D atlas of widely separated binary stars within about 3,000 light years of Earth—1.3 million of them.

The one-of-a-kind atlas, created by Kareem El-Badry, an astrophysics Ph.D. student from the University of California, Berkeley, should be a boon for those who study binary stars—which make up at least half of all sunlike stars—and white dwarfs, exoplanets and stellar evolution, in general. Before Gaia, the last compilation of nearby binary stars, assembled using data from the now-defunct Hipparcos satellite, included about 200 likely pairs.

"This is just a massive increase in sample size," said El-Badry. "And it is an increase in what kinds of evolutionary phases we find the binaries in. In our sample, we have 17,000 white dwarfs alone. This is a much bigger census."

White dwarfs are the end stages of most stars; the sun will likely end up as a compact white dwarf in 5 billion years. El-Badry's atlas includes 1,400 systems that consist of two white dwarfs and 16,000 binaries that consist of a white dwarf and another type of star

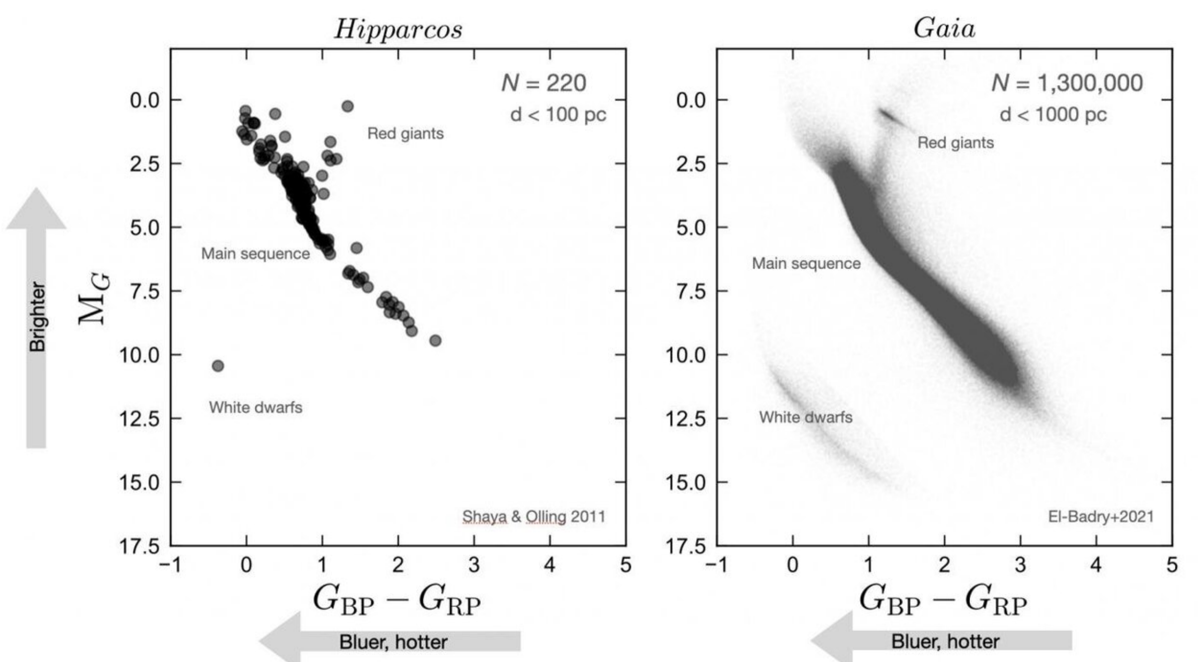
The vast majority of the 2.6 million individual stars are still in the prime of life, however. Astronomers refer to them as main sequence stars, because they cluster along a line when plotted on a graph showing temperature versus brightness.

With such a large sample size, El-Badry said, it's possible to do population demographics of these stellar twins, asking questions such as: What is the distribution of mass ratios of the two stars in all these binary systems? How are their separations or eccentricities distributed?

El-Badry plans to focus in the future on the white dwarf binaries, because white dwarfs can be assigned an age more precisely than is possible with regular stars. Main sequence stars like the sun can look the same for billions, or even tens of billions, of years, while white dwarfs change—for one thing, they cool down at a well-defined rate. And since binary pairs are birthed at the same time, the age of the white dwarf tells astronomers the age of its main-sequence twin, or of any planets around the stars.

"For a white dwarf, in general, it is easy to tell how old it is—not just how old since it became a white dwarf, but what its total age is," he said. "You can also measure their masses, because white dwarfs have a well-understood mass-radius relation."

As an example, El-Badry and colleagues recently used the Gaia data to estimate the age of a Jupiter-sized gas giant discovered by the TESS satellite around a white dwarf-K dwarf pair. That exoplanet, TOI-1259Ab, turned out to be about 4 billion years old, based on the age of the white dwarf.



When stars are plotted according to their color and brightness, they fall along a line called the main sequence, where they spend most of their lives, evolving into red giants and then white dwarfs only at the end of their lives. The previous survey of nearby binary stars found several hundred, whereas the newest atlas contains 1.3 million pairs, allowing astronomers to better understand the evolution of binary stars and stars in general. Credit: Kareem El-Badry, UC Berkeley

"In this catalog, there are something like 15 systems like this: star plus planet plus white dwarf," he said, "and there are another few hundred that are star plus planet plus another star. Those are also potentially interesting because, in some cases, the other star will do something dynamically to the planet."

The new catalog of nearby binary stars has been accepted for publication in the journal *Monthly Notices of the Royal Astronomical Society*.

El-Badry also collaborated with Jackie Faherty, a scientist and educator at the American Museum of Natural History in New York City, to create a video fly-through of all the million binary stars around Earth, which represents a good chunk of the entire Milky Way Galaxy.

Binary stars

Until Gaia was launched by the European Space Agency in 2013 to precisely measure the distances and motions of millions of nearby stars, the only way to find binaries was to look for stars close together in the sky. This can be tricky, because stars that look very close from Earth could be hundreds to thousands of light-years from one another, merely sitting along the same line of site.

Ruling out a chance alignment requires lots of observing time to confirm that the two candidates are actually at the same distance and moving together. Because of Earth's motion around the sun, nearby stars appear to change position in the sky, and that parallax can be used to calculate how far away they are. The star's motion across the sky, known as proper motion, helps determine its velocity.

Gaia conducts this tedious astrometry continuously for all nearby stars in the sky, 24/7, from its orbit at the Earth-Sun Lagrange point. The space telescope's survey is most useful for stars within about 3,000 light years of Earth, however, because beyond that, the parallax is usually too small to measure.

El-Badry first looked for binary stars in Gaia data after the mission's second release of star measurements in 2018, with the help of colleagues Hans-Walter Rix, director of the Max-Planck Institute for Astronomy in Heidelberg, Germany, and Tyler Heintz, a graduate student at Boston University. They developed computational techniques to identify stars moving together through space and at the same distance from Earth. The technique basically projects each star's movement over thousands of years, based on its proper motion today, and pulls out stars that are moving in the same direction. If they also turn out to be at the same distance based on parallax, they're probably bound to one another, he said.

He and his colleagues focus primarily on wide-binaries—those separated by a distance of 10 AU (astronomical units) or more—that is, 10 or more times the distance between Earth and the sun (93 million miles). Stars closer than that typically appear as one point of light and require other spectroscopic techniques to distinguish whether they are true binaries.

To get first crack at Gaia's latest data, El-Badry arose at 3 a.m. on the release date, Dec. 3 of last year, and joined some 100 other astronomers from around the world on Zoom. He quickly ran pre-programmed queries on the data to extract the catalog information he needed to create the 3-D map.

The initial queries returned some 1.8 million binary candidates from Gaia's catalog of 1.8 billion stars, so El-Badry first had to assess the likelihood that some of the pairs were at the same distance and moving in similar directions just by chance, not because they are paired. He estimates that nearly 1.3 million pairs had at least a 90% chance of being bound, and 1.1 million had a 99% chance.

"About half of all sun-like stars are binaries, many of them too close to distinguish, but we find something like 25% of all sun-like stars have a binary companion at separations of more than 30 AU, about the distance to Pluto," he said. "The distribution peaks at a separation of 30 or 50 AU."

Some pairs are separated by as much as a parsec—260,000 AU, or 3.26 light years—though most are within 1,000 AU of one another.

One takeaway, he said, is that the new analysis confirms something hinted at in the 2018 data: Many binary star pairs are very similar in mass.

"One thing we already found that is cool—we discovered this with Gaia DR2, but now we can study it better with this sample—is that binaries like to be identical twins," he said. "That is really weird, because most of these are separated by hundreds or thousands of AU, so they are so far apart that, by conventional star formation theories, their masses should be random. But the data tells a different story: They know something about their companions' masses."

The implication, he said, is that they formed much closer together in a process that tended to equalize their masses and then migrated apart, perhaps because of interactions with other nearby stars.

The compilation of binary stars also allowed El-Badry to check the reported uncertainties in Gaia's measurements of stellar positions, which can assist other researchers who use the data.

More information: Kareem El-Badry et al, A million binaries from Gaia eDR3: sample selection and validation of Gaia parallax uncertainties, *Monthly Notices of the Royal Astronomical Society* (2021). DOI: 10.1093/mnras/stab323

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