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Astronomers measure the mass of the Milky Way by calculating how hard it is to escape

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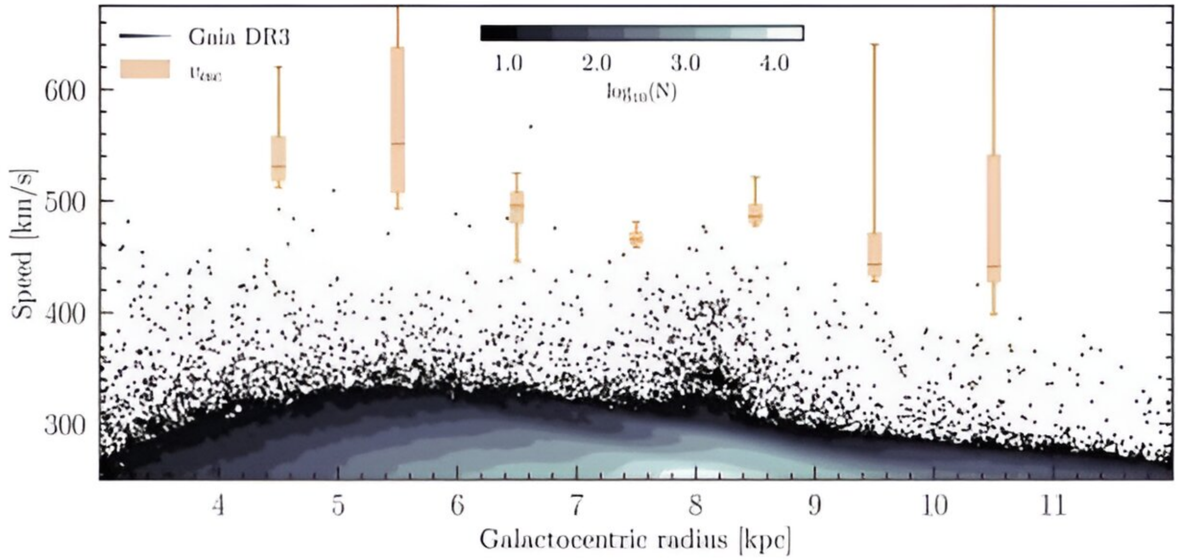
Artist view of the Milky Way galaxy. Credit: ESA

If you want to determine your mass, it's pretty easy. Just step on a scale and look at the number it gives you. That number tells you the gravitational pull of Earth upon you, so if you feel the number is too high, take comfort that Earth just finds you more attractive than others. The same scale could also be used to measure the mass of Earth. If you place a kilogram mass on the scale, the weight it gives is also the weight of Earth in the gravitational field of the kilogram. With a bit of mass, you have the mass of Earth.

Things aren't quite that simple. The Earth is not a perfectly spherical, perfectly uniform mass, so its gravitational pull varies slightly across the globe. But this method gives a reasonable ballpark value, and we can use it to estimate the masses of other objects in the solar system. But how can we determine the mass of something larger, such as the Milky Way? One method is to estimate the number of stars in the galaxy and their masses, then estimate the mass of all the interstellar gas and dust, and then rough out the amount of dark matter… it all gets very complicated.

A better way is to look at how the orbital speed of stars varies with distance from the galactic center. This is known as the rotation curve and gives an upper mass limit on the Milky Way, which seems to be around 600 billion to a trillion solar masses. The wide uncertainty gives you an idea of just how difficult it is to measure our galaxy's mass. But a new study posted to the *arXiv* preprint server introduces a new method, and it could help astronomers pin things down.

The method looks at the escape velocity of stars in our galaxy. If a star is moving fast enough, it can overcome the gravitational pull of the Milky Way and escape into interstellar space. The minimum speed necessary to escape depends upon our galaxy's mass, so measuring one gives you the other. Unfortunately, only a handful of stars are known to be escaping, which is not enough to get a good handle on galactic mass. So the team looked at the statistical distribution of stellar speeds as measured by the Gaia spacecraft.



Estimated escape velocities at different galactic radii. Credit: Roche et al

The method is similar to weighing the moon with a handful of dust. If you were standing on the moon and tossed dust upward, the slower-moving dust particles would reach a lower height than faster particles. If you measured the speeds and positions of the dust particles, the statistical relation between speed and height would tell you how strongly the moon pulls on the motes, and thus the mass of the moon. It would be easier just to bring our kilogram and scale to measure lunar mass, but the dust method could work.

In the Milky Way, the stars are like dust motes, swirling around in the gravitational field of the galaxy. The team used the speeds and positions of a billion stars to estimate the escape velocity at different distances from the galactic center. From that, they could determine the overall mass of the Milky Way. They calculated a mass of 640 billion suns.

This is on the lower end of earlier estimates, and if accurate it means that the Milky Way has a bit less dark matter than we thought.

More information: Cian Roche et al, The Escape Velocity Profile of the Milky Way from Gaia DR3, *arXiv* (2024). DOI: 10.48550/arxiv.2402.00108

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