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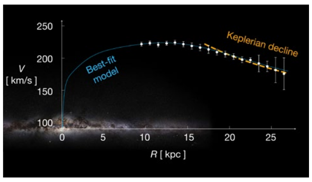
Press release

The revisited mass of the Milky Way is much smaller than expectations from cosmology

(Under embargo until 27 September 2023 – 10:00 am CEST)



Credits: Jiao, Hammer and al. / Observatoire de Paris – PSL / CNRS / ESA / Gaia / ESO / S. Brunier

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Thanks to the latest Gaia satellite catalogue from the European Space Agency (ESA), an international team led by astronomers from the Paris Observatory – PSL University and the CNRS has achieved the most accurate measurement of the mass of the Milky Way. Published in the *Astronomy and Astrophysics* journal on September 27, 2023, this study opens important questions in cosmology, particularly on the amount of dark matter contained in our Galaxy.

The total mass of the Milky Way is estimated to be only two hundred billion times that of the Sun ($2.06 \ 10^{11}$ solar masses), marking a significant downward revision—approximately four to five times lower than previous estimates.

This new value was derived from the third data release of the Gaia catalogue published in 2022, which provides comprehensive data for 1.8 billion stars, encompassing all three spatial components and three velocity components in a six-dimensional space within the Milky Way.

The bearable lightness of the Milky Way

Using the Gaia data, scientists were able to construct the most accurate rotation curve[1] ever observed for a spiral galaxy, in this case our own Galaxy, and deduce its mass. Prior to Gaia, obtaining a robust rotation curve for our Galaxy was challenging, unlike the case for external spiral galaxies. This challenge stemmed from our position within the Milky Way, which made it impossible to precisely distinguish the motions and distances of stars in the galactic disk.

In the study published on September 27, 2023, in the journal Astronomy and Astrophysics, the rotation curve of our Galaxy is atypical: unlike those determined for other large spiral galaxies, it is not flat. On the contrary, at the outskirts of the disk of the Galaxy, this curve begins to decrease rapidly, following the prediction known as the Keplerian decline[2].

Questioning cosmology

Obtaining a rotation curve for the Milky Way that exhibits a Keplerian decline necessitates situating our Galaxy within a cosmological framework.

Indeed, one of the major breakthroughs in modern astronomy was the realization that rotational velocities of the large disks of spiral galaxies were much faster than what

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[1] A rotation curve gives the circular velocity in function of the radius (see Figure)
[2] Satellites in orbit around a main body have speeds that follow the universal gravitational laws, called Kepler's laws. The further a satellite is from its main body, the slower its rotation speed, because its distance implies a smaller gravitational attraction. This decrease in speed is called Keplerian decline, and it is observed for planets of the Solar system.

would be expected from a Keplerian decline. In the 1970s, astronomers Vera Rubin, who used observations of ionized gas, and Albert Bosma, who studied neutral gas, demonstrated that the rotation speed of spiral galaxies remains constant, well beyond their optical discs. The immediate consequence of this discovery was the proposition of the existence of dark matter —additional to observable matter — distributed in a halo surrounding the disks of spiral galaxies, which dominates the galaxy mass. Without this dark matter, the rotation curves would have followed a decline called «Keplerian». The latter indicates the absence of significant amounts of matter outside the optical disk.

This is the case for the Milky Way, according to the current study. Considering that the ordinary matter (stars and cold gas) of the Milky Way is generally estimated to be just over 0.6×10^{11} solar masses, it accounts for approximately one-third of the total matter, letting the dark matter mass to be only two times that of the ordinary matter. This constitutes a revolution in cosmology, since until now it was agreed that dark matter should be at least six times more abundant than ordinary matter.

Two tentative explanations

If the majority of other large spiral galaxies do not exhibit a rotation curve with a Keplerian decline, what makes our Galaxy so different?

One possible explanation may come from the fact that the Milky Way has experienced relatively few disruptions from violent collisions between galaxies. Its last major merger occurred approximately 9 billion years ago, in contrast to the average of 6 billion years for other spiral galaxies. In any case, this indicates that the rotation curve obtained for the Milky Way is particularly accurate, not being affected by the residues of such an old collision.

The second possibility may come from the methodological differences between the rotation curve derived from the six-dimensional data of stars that is delivered by the Gaia satellite, our Galaxy for instance, and the rotation curves derived using neutral gas for other galaxies.

This work paves the way for a reassessment of the rotation curves of large spiral galaxies and their content in ordinary and dark matter.

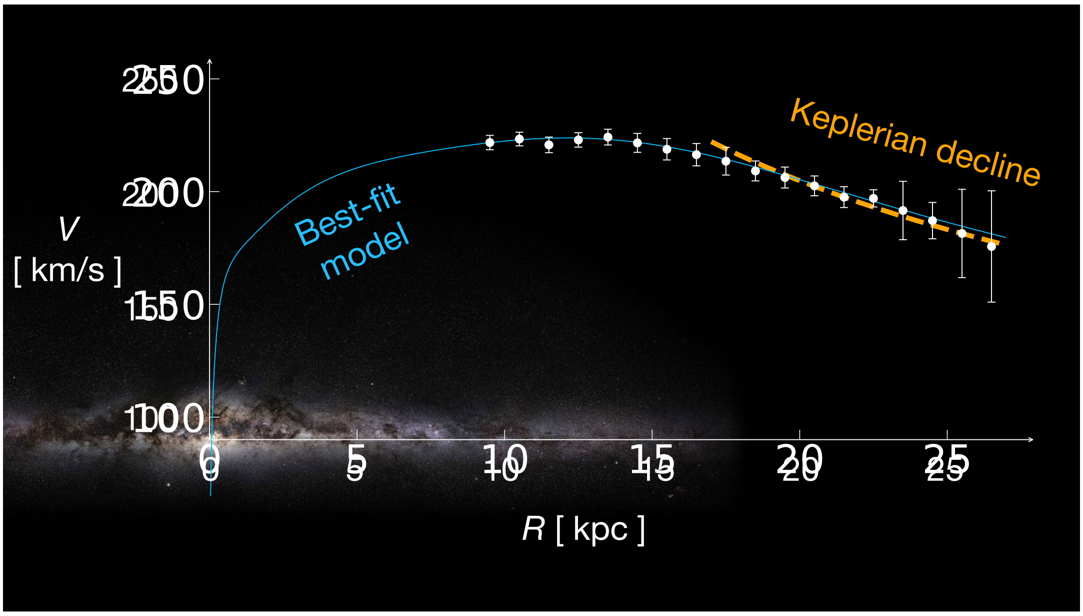
Reference

The article '*Detection of the Keplerian decline in the Milky Way rotation curve*' by Yongjun Jiao and al. (2023) is published in *Astronomy & Astrophysics*, on September 27, 2023.
DOI: 10.1051/0004-6361/202347513
Article can be also find at: https://arxiv.org/abs/2309.00048

International Collaboration

The team includes researchers from Paris Observatory – PSL University, CNRS, Centro Ricerche Enrico Fermi (Rome, Italie), CAS Key Laboratory (Beijing, Chine), Aix-Marseille University (Marseille, France) and the Institut de Astrofisica (Santiago, Chili).

Image



Caption: The Milky Way rotation curve representing the circular rotational speed of stars as a function of distance to the Galactic center. The white dots and error bars represent the measurements obtained from the Gaia DR3 catalog. The blue curve represents the best adjustment of the rotation curve by a model including ordinary matter and dark matter. The yellow part of the curve shows the Keplerian decline with V decreasing as $R^{-1/2}$, which begins beyond the optical disk of our Galaxy. It means that beyond the Galaxy optical disk, its gravitational attraction is similar to that of a point mass. A constant rotation speed is rejected with a probability of 99,7% (3σ).

Credits: Jiao, Hammer et al. / Observatoire de Paris – PSL / CNRS / ESA / Gaia / ESO / S. Brunier