Gaia clocks new speeds for Milky Way-Andromeda collision

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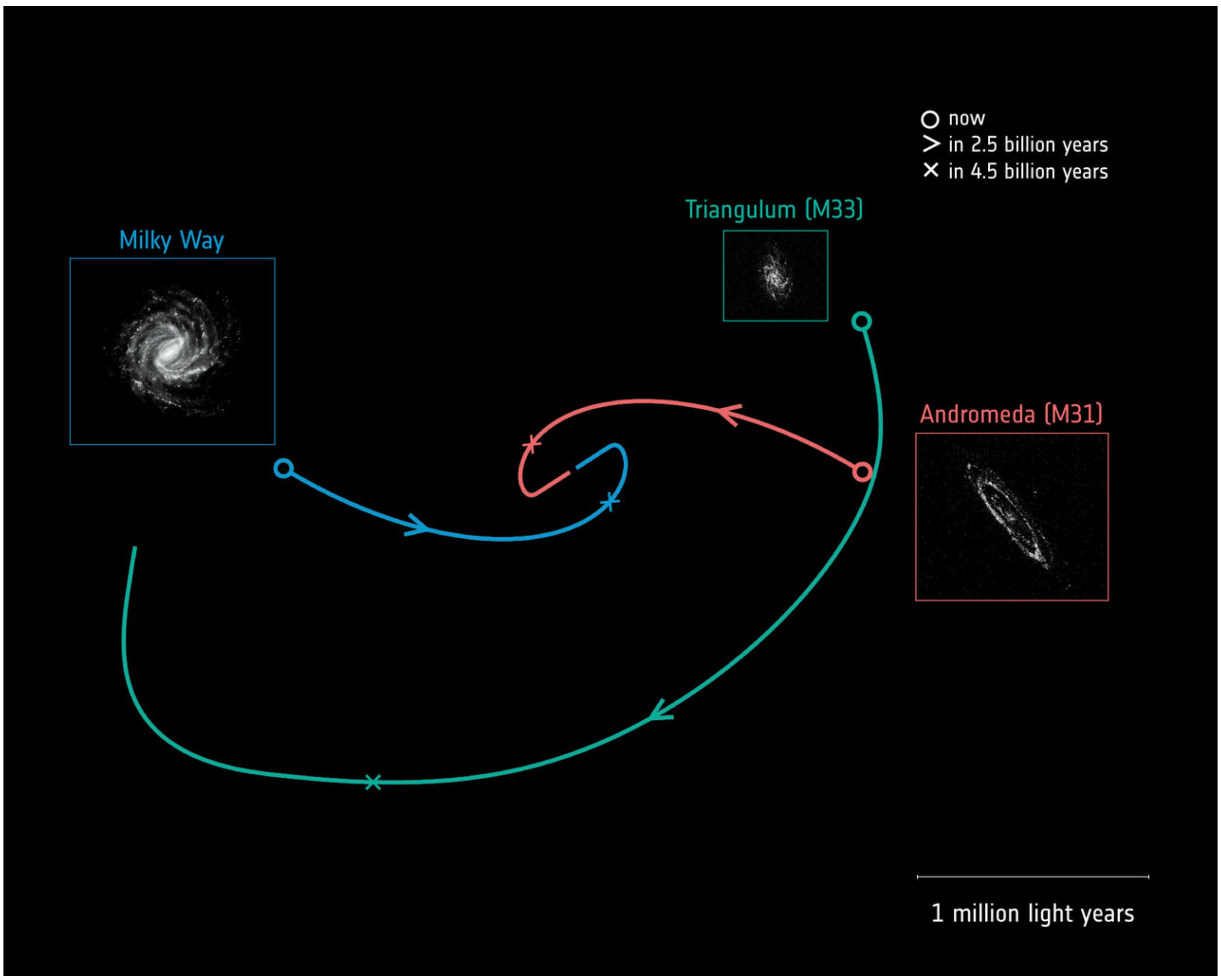


The future orbital trajectories of three spiral galaxies: our Milky Way (blue), Andromeda, also known as M31 (red), and Triangulum, also known as M33 (green). The circle indicates the current position of each galaxy, and their future trajectories have been calculated using data from the second release of ESA's Gaia mission. The Milky Way is shown as an artist's impression, while the images of Andromeda and Triangulum are based on Gaia data. Arrows along the trajectories indicate the estimated direction of each galaxy's motion and their positions, 2.5 billion years into the future, while crosses mark their estimated position in about 4.5 billion years. Approximately 4.5 billion years from now, the Milky Way and Andromeda will make their first close passage around one another at a distance of approximately 400 000 light-years. The galaxies will then continue to move closer to one another and eventually merge to form an elliptical galaxy. The linear scale of 1 million light years refers to the galaxy trajectories; the galaxy images are not to scale. Credit: Orbits: E. Patel, G. Besla (University of Arizona), R. van der Marel (STScI); Images: ESA (Milky Way); ESA/Gaia/DPAC (M31, M33)

ESA's Gaia satellite has looked beyond our Galaxy and explored two nearby galaxies to reveal the stellar motions within them and how they will one day interact and collide with the Milky Way – with surprising results.

Our Milky Way belongs to a large gathering of galaxies known as the Local Group and, along with the Andromeda and Triangulum galaxies – also referred to as M31 and M33, respectively – makes up the majority of the group's mass.

Astronomers have long suspected that Andromeda will one day collide with the Milky Way, completely reshaping our cosmic neighbourhood. However, the three-dimensional movements of the Local Group galaxies remained unclear, painting an uncertain picture of the Milky Way's future.

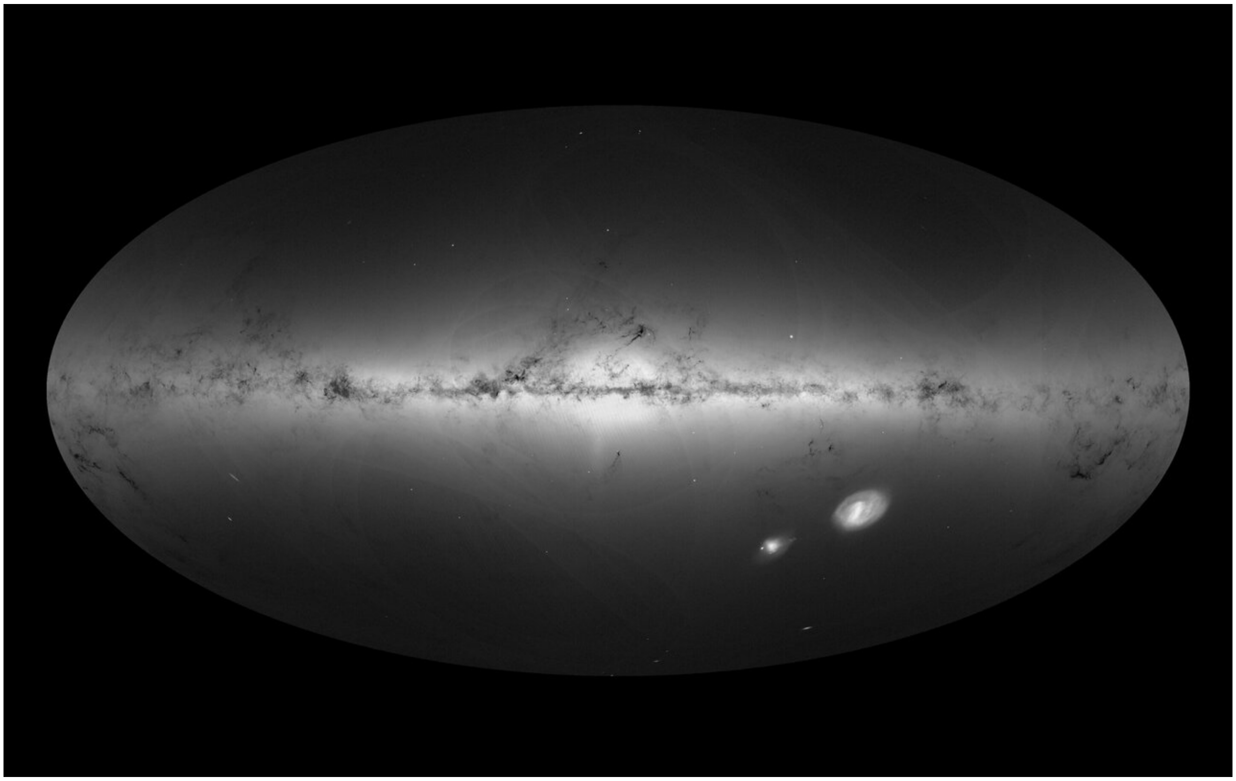
"We needed to explore the galaxies' motions in 3D to uncover how they have grown and evolved, and what creates and influences their features and behaviour," says lead author Roeland van der Marel of the Space Telescope Science Institute in Baltimore, USA.

"We were able to do this using the second package of high-quality data released by Gaia."

Gaia is currently building the most precise 3D map of the stars in the nearby Universe, and is releasing its data in stages. The data from the second release, made in April 2018, was used in this research.

Previous studies of the Local Group have combined observations from telescopes including the NASA/ESA Hubble Space Telescope and the ground-based Very Long Baseline Array to figure out how the orbits of Andromeda and Triangulum have changed over time. The two disc-shaped spiral galaxies are located between 2.5 and 3 million light-years from us, and are close enough to one another that they may be interacting.

Two possibilities emerged: either Triangulum is on an incredibly long six-billion-year orbit around Andromeda but has already fallen into it in the past, or it is currently on its very first infall. Each scenario reflects a different orbital path, and thus a different formation history and future for each galaxy.



An all-sky view of our Milky Way Galaxy and neighbouring galaxies, based on measurements of nearly 1.7 billion stars. The map shows the density of stars observed by Gaia in each portion of the sky between July 2014 to May 2016. Brighter regions indicate denser concentrations of stars, while darker regions correspond to patches of the sky where fewer stars are observed. In contrast to the brightness map in colour, which is dominated by the brightest and most massive stars, this view shows the distribution of all stars, including faint and distant ones. The bright horizontal structure that dominates the image is the Galactic plane, the flattened disc that hosts most of the stars in our home Galaxy, with the Galactic centre in the middle. The elongated feature visible below the Galactic centre and pointing in the downwards direction is the Sagittarius dwarf galaxy, a small satellite of the Milky Way that is leaving a stream of stars behind as an effect of our Galaxy's gravitational tug. This faint feature is only visible in this view, and not in the all-sky map based on the luminosity of stars, which is dominated by bright sources. Darker regions across the Galactic plane correspond to foreground clouds of interstellar gas and dust, which absorb the light of stars located further away, behind the clouds. Many of these conceal stellar nurseries where new generations of stars are being born. Sprinkled across the image are also many globular and open clusters – groupings of stars held together by their mutual gravity, as well as entire galaxies beyond our own. The two bright objects in the lower right of the image are the Large and Small Magellanic Clouds, two dwarf galaxies orbiting the Milky Way. Other nearby galaxies are also visible, most notably the Milky Way's largest galactic neighbour the Andromeda galaxy (also known as M31), seen in the lower left of the image along with its satellite, the Triangulum galaxy (M33). A number of artefacts are also visible on the image in the form of curved features and darker stripes, though in much lesser extent with respect to Gaia's first map of the sky, which was based on only 14 months of the satellite's data. These features are not of astronomical origin but rather reflect Gaia's scanning procedure, and will gradually fade away as more data are gathered during the five-year mission. The second Gaia data release was made public on 25 April 2018 and includes the position and brightness of almost 1.7 billion stars, and the parallax, proper motion and colour of more than 1.3 billion stars. It also includes the radial velocity of more than seven million stars, the surface temperature of more than 100 million and other astrophysical parameters of 70–80 million stars. There are also more than 500 000 variable sources, and the position of 14 099 known Solar System objects – most of them asteroids – included in the release. Credit: ESA/Gaia/DPAC, CC BY-SA 3.0 IGO

While Hubble has obtained the sharpest view ever of both Andromeda and Triangulum, Gaia measures the individual position and motion of many of their stars with unprecedented accuracy.

"We combed through the Gaia data to identify thousands of individual stars in both galaxies, and studied how these stars moved within their galactic homes," adds co-author Mark Fardal, also of Space Telescope Science Institute.

"While Gaia primarily aims to study the Milky Way, it's powerful enough to spot especially massive and bright stars within nearby star-forming regions – even in galaxies beyond our own."

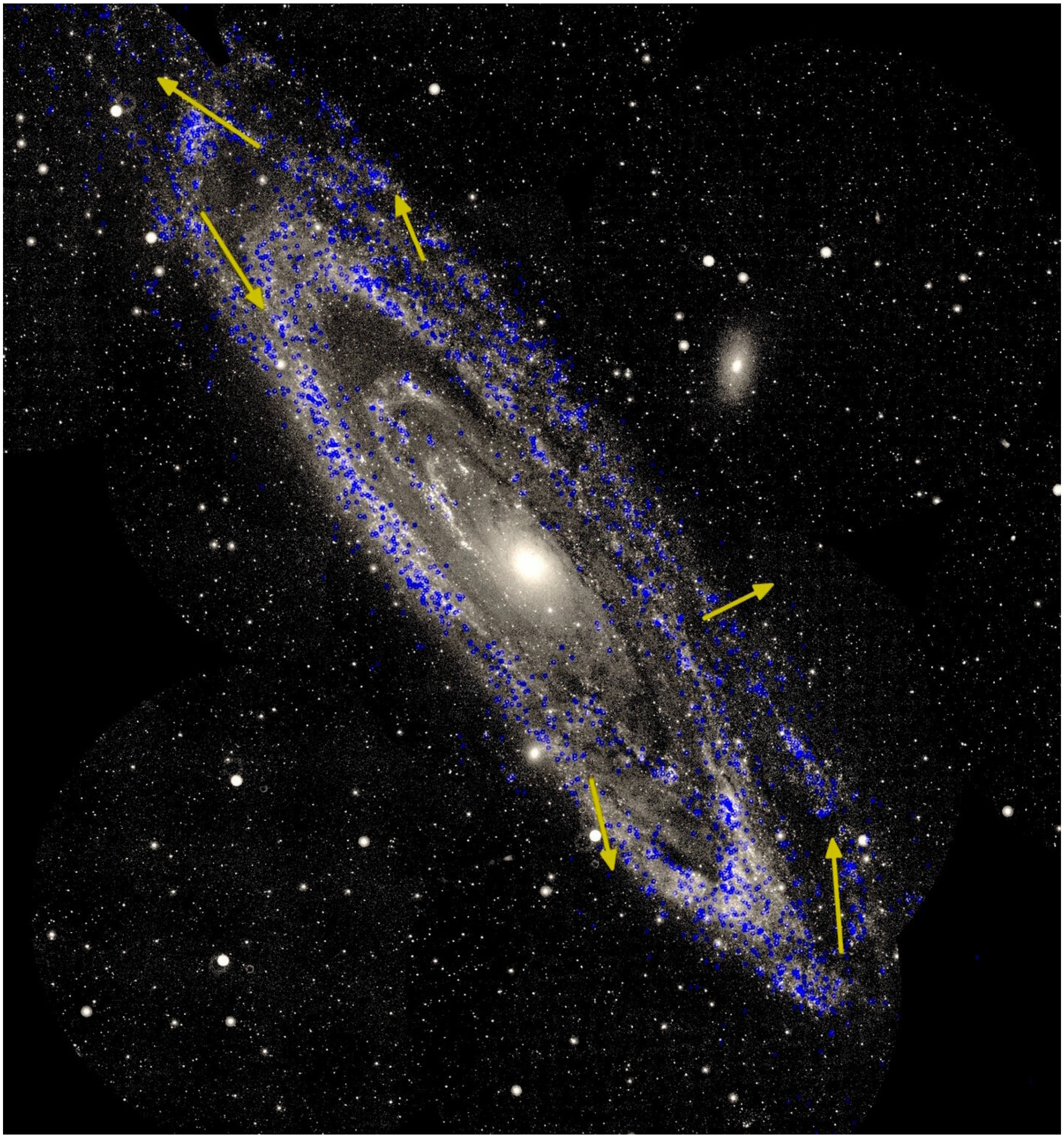
The stellar motions measured by Gaia not only reveal how each of the galaxies moves through space, but also how each rotates around its own spin axis.

A century ago, when astronomers were first trying to understand the nature of galaxies, these spin measurements were much sought-after, but could not be successfully completed with the telescopes available at the time.

"It took an observatory as advanced as Gaia to finally do so," says Roeland.

"For the first time, we've measured how M31 and M33 rotate on the sky. Astronomers used to see galaxies as clustered worlds that couldn't possibly be separate 'islands', but we now know otherwise.

"It has taken 100 years and Gaia to finally measure the true, tiny, rotation rate of our nearest large galactic neighbour, M31. This will help us to understand more about the nature of galaxies."



A view of the Andromeda galaxy, also known as M31, with measurements of the motions of stars within the galaxy. This spiral galaxy is the nearest large neighbor of our Milky Way. The background image, obtained with NASA's Galex satellite at near-ultraviolet wavelengths, highlights regions within the galaxy where stars are forming. Blue symbols mark the locations of bright young stars that were used to measure the motion of the galaxy, and yellow arrows indicate the average stellar motions at various locations, based on data from the second release of

ESA's Gaia satellite. A counter-clockwise rotation of the spiral galaxy's disc is evident. The precision of these measurements is expected to improve with the future Gaia data releases. Credit: ESA/Gaia (star motions); NASA/Galex (background image); R. van der Marel, M. Fardal, J. Sahlmann (STScI)

By combining existing observations with the new data release from Gaia, the researchers determined how Andromeda and Triangulum are each moving across the sky, and calculated the orbital path for each galaxy both backwards and forwards in timefor billions of years.

"The velocities we found show that M33 cannot be on a long orbit around M31," says co-author Ekta Patel of the University of Arizona, USA. "Our models unanimously imply that M33 must be on its first infall into M31."

While the Milky Way and Andromeda are still destined to collide and merge, both the timing and destructiveness of the interaction are also likely to be different than expected.

As Andromeda's motion differs somewhat from previous estimates, the galaxy is likely to deliver more of a glancing blow to the Milky Way than a head-on collision. This will take place not in 3.9 billion years' time, but in 4.5 billion – some 600 million years later than anticipated.

"This finding is crucial to our understanding of how galaxies evolve and interact," says Timo Prusti, ESA Gaia Project Scientist.

"We see unusual features in both M31 and M33, such as warped streams and tails of gas and stars. If the galaxies haven't come together before, these can't have been created by the forces felt during a merger. Perhaps they formed via interactions with other galaxies, or by gas dynamics within the galaxies themselves.

"Gaia was designed primarily for mapping stars within the Milky Way—but this new study shows that the satellite is exceeding expectations, and can provide unique insights into the structure and dynamics of galaxies beyond the realm of our own. The longer Gaia watches the tiny movements of these galaxies across the sky, the more precise our measurements will become."

More information: Roeland P. van der Marel et al. First Gaia Dynamics of the Andromeda System: DR2 Proper Motions, Orbits, and Rotation of M31 and M33, *The Astrophysical Journal* (2019). DOI: 10.3847/1538-4357/ab001b

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