Einstein and Euler: Accelerating expansion of the universe and dark matter theories put to the test

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The cosmos is a unique laboratory for testing the laws of physics, in particular those of Euler and Einstein. Euler described the movements of celestial objects, while Einstein described the way in which celestial objects distort the universe.

Since the discovery of dark matter and the acceleration of the universe's expansion, the validity of their equations has been put to the test: are they capable of explaining these mysterious phenomena? A team from the University of Geneva (UNIGE) has developed the first method to find out. It considers a never-before-used measure—time distortion. The results are published in *Nature Astronomy*.

The theories of Leonhard Euler (1707–1783) and Albert Einstein (1879–1955) revolutionized our understanding of the universe. With the famous equation that bears his name, Euler gave scientists a powerful tool for calculating the movements of galaxies in the universe. With his theory of general relativity, Einstein demonstrated that the universe is not a static framework—it can be distorted by star clusters and galaxies.

Physicists have tested these equations in all sorts of ways, which have so far proved successful. However, two discoveries continue to put these models to the test: the acceleration of the universe's expansion and the existence of invisible dark matter, which is thought to account for 85% of all matter in the cosmos. Do these mysterious phenomena still obey the equations of Einstein and Euler? Researchers are still unable to answer this question.

The missing ingredient

"The problem is that current cosmological data do not allow us to differentiate between a theory that breaks Einstein's equations and one that breaks Euler's equation. This is what we demonstrate in our study. We also present a mathematical method for solving this problem. This is the culmination of 10 years of research," explains Camille Bonvin, associate professor in the Department of Theoretical Physics in the UNIGE Faculty of Science and first author of the study.

Researchers were unable to differentiate between the validity of these two equations at the very edge of the universe because they were missing an "ingredient"—the measurement of time distortion. "Until then, we only knew how to measure the speed of celestial objects and the sum of the distortion of time and space. We have developed a method for accessing this additional measurement, and it's a first," says Camille Bonvin.

If the time distortion is not equal to the sum of time and space—i.e., the result produced by the theory of general relativity—this means that Einstein's model does not work. If the time distortion does not correspond to the speed of the galaxies calculated with the Euler equation, this means that the latter is not valid. "This will allow us to discover whether new forces or matter, which violate these two theories, exist in the universe," explains Levon Pogosian, professor in the Department of Physics at Simon Fraser University, in Canada, and co-author of the study.

Reality check

These results will make a crucial contribution to several missions whose aim is to determine the origin of the accelerated expansion of the universe and the nature of dark matter. These include the EUCLID space telescope, which will be launched in July 2023 by the European Space Agency (ESA), in collaboration with the UNIGE, and the Dark Energy Spectroscopic Instrument (DESI), which began its five-year mission in 2021 in Arizona. There is also the international SKA (Square Kilometer Array) giant radio telescope project in South Africa and Australia, which will begin observations in 2028/29.

"Our method will be integrated into these different missions. This is already the case for DESI, whom we have become external collaborators thanks to this research," Camille Bonvin says. The research team has successfully tested its model on synthetic catalogs of galaxies. The next stage will involve testing it using the first data supplied by DESI, as well as identifying the obstacles and minimizing the systematic features that could hamper its application.

More information: Camille Bonvin et al, Modified Einstein versus Modified Euler for Dark Matter, *Nature Astronomy* (2023). DOI: 10.1038/s41550-023-02003-y. On *arXiv*: arxiv.org/abs/2209.03614

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