Acceleration relation found among spiral and irregular galaxies challenges current understanding of dark matter

September 21 2016

In spiral galaxies such as NGC 6946, researchers found that a 1-to-1 relationship between the distribution of stars plus gas and the acceleration caused by gravity exists.

In the late 1970s, astronomers Vera Rubin and Albert Bosma independently found that spiral galaxies rotate at a nearly constant speed: the velocity of stars and gas inside a galaxy does not decrease with radius, as one would expect from Newton's laws and the distribution of visible matter, but remains approximately constant. Such 'flat rotation curves' are generally attributed to invisible, dark matter surrounding galaxies and providing additional gravitational attraction.

Now a team led by Case Western Reserve University researchers has found a significant new relationship in spiral and irregular galaxies: the acceleration observed in rotation curves tightly correlates with the gravitational acceleration expected from the visible mass only.

"If you measure the distribution of star light, you know the rotation curve, and vice versa," said Stacy McGaugh, chair of the Department of Astronomy at Case Western Reserve and lead author of the research.

The finding is consistent among 153 spiral and irregular galaxies, ranging from giant to dwarf, those with massive central bulges or none at all. It is also consistent among those galaxies comprised of mostly stars or mostly gas.

In a paper accepted for publication by the journal *Physical Review Letters* and posted on the preprint website arXiv, McGaugh and co-authors Federico Lelli, an astronomy postdoctoral scholar at Case Western Reserve, and James M. Schombert, astronomy professor at the University of Oregon, argue that the relation they've found is tantamount to a new natural law.

An astrophysicist who reviewed the study said the findings may lead to a new understanding of internal dynamics of galaxies.

"Galaxy rotation curves have traditionally been explained via an ad hoc hypothesis: that galaxies are surrounded by dark matter," said David Merritt, professor of physics and astronomy at the Rochester Institute of Technology, who was not involved in the research. "The relation discovered by McGaugh et al. is a serious, and possibly fatal, challenge to this hypothesis, since it shows that rotation curves are precisely determined by the distribution of the normal matter alone. Nothing in the standard cosmological model predicts this, and it is almost impossible to imagine how that model could be modified to explain it, without discarding the dark matter hypothesis completely."

McGaugh and Schombert have been working on this research for a decade and with Lelli the last three years. Near-infrared images collected by NASA's Spitzer Space Telescope during the last five years allowed them to establish the relation and that it persists for all 153 galaxies.

The key is that near-infrared light emitted by stars is far more reliable than optical-light for converting light to mass, Lelli said.

The researchers plotted the radial acceleration observed in rotation curves published by a host of astronomers over the last 30 years against the acceleration predicted from the observed distribution of ordinary matter now in the Spitzer Photometry & Accurate Rotation Curves database McGaugh's team created. The two measurements showed a single, extremely tight correlation, even when dark matter is supposed to dominate the gravity.

"There is no intrinsic scatter, which is how far the data differ on average from the mean when plotted on a graph," McGaugh said. "What little scatter is found is consistent with stellar mass-to-light ratios that vary a little from galaxy to galaxy."

Lelli compared the relation to a long-used natural law. "It's like Kepler's third law for the solar system: if you measure the distance of each planet from the sun, you get the orbital period, or vice versa" he said. "Here we have something similar for galaxies, with about 3,000 data points."

"In our case, we find a relation between what you see in normal matter in galaxies and what you get in their gravity," McGaugh said. "This is important because it is telling us something fundamental about how galaxies work."

Arthur Kosowsky, professor of physics and astronomy at the University of Pittsburgh, was not involved but reviewed the research.

"The standard model of cosmology is remarkably successful at explaining just about everything we observe in the universe," Kosowsky said. "But if there is a single observation which keeps me awake at night worrying that we might have something essentially wrong, this is it."

He said McGaugh and collaborators have steadily refined the spiral galaxy scaling relation for years and called this latest work a significant advance, reducing uncertainty in the mass in normal matter by exploiting infrared observations.

"The result is a scaling relation in the data with no adjustable parameters," Kosowky said. "Throughout the history of physics, unexplained regularities in data have often pointed the way towards new discoveries."

McGaugh and his team are not pressing any theoretical interpretation of their empirical relation at this point.

"The natural inference is that this law stems from a universal force such as a modification of gravity like MOND, the hypothesis of Modified Newtonian Dynamics proposed by Israeli physicist Moti Milgrom. But it could also be something in the nature of dark matter like the superfluid dark matter proposed by Justin Khoury," McGaugh said. "Most importantly, whatever theory you want to build has to reproduce this."

More information: Radial acceleration relation in rotationally supported galaxies. arxiv.org/abs/1609.05917

Provided by Case Western Reserve University