COMMENTARY

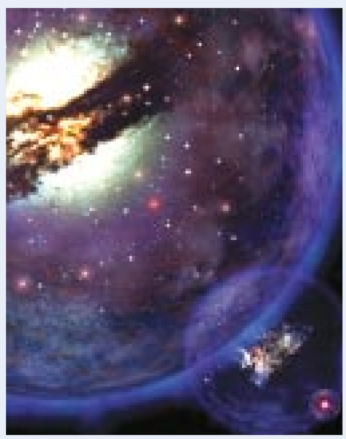
Not a Bad Idea

MOND is out of the mainstream, but it is far from wacky

By Anthony Aguirre

Although the great majority of astronomers believe that dark matter exists, an alternative hypothesis—a modification of Newtonian gravitational dynamics (MOND)—has quietly endured since its proposal in 1983. As Mordehai Milgrom discusses in the accompanying article, MOND can claim an impressive number of correct predictions regarding the dynamics of galaxies. The reactions of most astronomers fall into three categories:

1. MOND is a tautology. It explains only what it was expressly designed to explain. It has made a few fortuitous predictions, but the success of those predictions has been exaggerated by its proponents.
2. MOND describes a surprising, even mysterious, regularity in the formation and evolution of galaxies. The standard theory of gravity still applies and dark matter still exists, but somehow the dark matter emulates MOND. When applied in detail to unusual galaxies or to systems other than galaxies, MOND will eventually be shown to fail.
3. MOND replaces Newtonian dynamics under certain conditions. It is one aspect of a theory of gravitational dynamics that will supplant Einstein's general theory of relativity.



The first view, through uncharitable, was the one held by most astrophysicists for much of MOND's history. In recent years, however, outright rejection has become much less tenable. MOND's myriad predictions have been confirmed. Many of these studies have been performed by those critical of, or neutral toward, Milgrom's hypothesis. Moreover, MOND reproduces the statistics of galaxy properties at least as well as dark matter models do, even though these models describe crucial aspects of galaxy formation in an ad hoc way.

Most impressively, MOND can predict the details of galaxy rotation using only the distribution of visible matter and an assumed (fixed) ratio of mass to luminosity—a feat beyond the ability of dark matter models. These predictions and the observations they are compared with go far beyond what was available at the time of MOND's formulation. MOND is no tautology.

Meanwhile standard dark matter theory has run into difficulty when applied to galaxies. For example, it predicts that the dark matter cores of galaxies should be far denser than observations indicate. Such problems could be an artifact of computational limitations; researchers still lack computers powerful enough to simulate galaxies in full. But many theorists have taken the discrepancies seriously enough to consider modifications of the properties of dark matter.

The successes of MOND and the difficulties for dark matter have converted a number of astronomers from the first view to the second. Relatively few, though, have gone from the first or second view to the third. Why? I think there are three reasons.

First, as both its opponents and proponents point out, MOND is a modification only of Newtonian dynamics. Despite some effort, MOND's proponents have yet to formulate it in a way that can be applied to post-Newtonian phenomena such as gravitational lensing and cosmic expansion. Either no such theory exists or it is inherently difficult to develop. Whatever the reason, MOND has been unable to confront—and hence pass or fail—some key tests.

Second, it is not clear that MOND works well in systems other than galaxies. For example, its predictions about the temperature of hot gas in clusters of galaxies disagree starkly with observations, unless clusters are dominated by—what else?—undetected matter. One might hope (as do MOND's proponents) that this matter could take a recognizable but hard-to-see baryonic form such as small stars or warm gas. Those possibilities are not currently ruled out, but they are strongly constrained both observationally and theoretically. And it is rather disquieting that dark matter (even if in a prosaic form) must be postulated to save a theory devised to eliminate dark matter.

The third reason, related to the first two, is that standard dark matter theory has scored some impressive triumphs in recent years. Numerical simulations predict a spatial distribution of intergalactic gas that is in exquisite agreement with observations. Independent estimates of the mass of dark matter in clusters all agree with one another. The predicted growth of structures correctly links the galaxy distribution we see on large scales today with the tiny temperature fluctuations in the cosmic microwave background radiation from 13 billion years ago.

So what are astronomers to do? Those who are most sympathetic to Milgrom's hypothesis should continue the search for a fundamental theory of MOND, without which the idea will never draw the majority of physicists away from the standard paradigm. For others, I think that it is productive to study, test and use MOND as a convenient rule of thumb whether or not one accepts a modification of Newtonian dynamics. Perhaps we could call it Milgrom's Fitting Formula, or MIFF, to emphasize that we are using it as a practical tool while reserving judgment about whether standard physics is indeed wrong.

If general relativity is correct, and dark matter real, then as the precision of measurements increases, MIFF will ultimately fail. In the meantime, MIFF can provide a compact summary of a great deal of knowledge concerning galaxy formation and evolution.

Anthony Aguirre is a theoretical cosmologist at the Institute for Advanced Study in Princeton, N.J. He is the lead author of two critical studies of MOND, available online at ***arXiv.org/abs/astro-ph/0105184*** *and* ***arXiv.org/abs/hep-ph/0105083***

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