Testing MOND with Ultra-Compact Dwarf Galaxies

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ABSTRACT
The properties of the recently discovered Ultra-Compact Dwarf Galaxies (UCDs) show that their internal acceleration of gravity is everywhere above \(a_0\), the MOdified Newtonian Dynamics (MOND) constant of gravity. MOND therefore makes the strong prediction that no mass discrepancy should be observed for this class of objects. This is confirmed by the few UCDs for which virial masses were derived. We argue that UCD galaxies represent a suitable test-bench for the theory, in the sense that even a single UCD galaxy showing evidence for dark matter would seriously question the validity of MOND.

Key words: Galaxies: astrophysics, external galaxies; gravitation: astrophysics – dark matter – galaxies: kinematics and dynamics

1 INTRODUCTION
Dwarf galaxies have attracted the attention of astrophysicists in the last years for many reasons. Among others, these galaxies are found to contain an impressive amount of non-baryonic dark matter having mass-to-light ratios up to 100 and being dark matter dominated all the way to their center (Mateo 1988, Kleya et al. 2001, 2004).

The discovery (Hilker et al. 1999; Drinkwater et al. 2000; Phillips et al. 2001) in an all-object survey of the Fornax cluster of a new type of galaxies, the ultra-compact dwarfs (UCD), have added a new member to the dwarf family. Unlike other dwarfs, however, UCD galaxies have very high central concentration and thus star-like morphology in typical one-arcsecond-resolution ground-based imaging. At the distance of the Fornax cluster (20 Mpc; Hubble constant \(H_0 = 75\) km s\(^{-1}\) Mpc\(^{-1}\)) this implies sizes of 100 pc at most. The absolute magnitudes range from \(-11 < M_B < -13\), significantly brighter than the brightest globular cluster known (Meylan et al. 2001). Thus, UCDs are squarely placed midway between regular dwarf galaxies and globular clusters.

Recent determination (Drinkwater et al. 2003) of their effective radius (ranging from 10 to 22 pc) and velocity dispersion (ranging from 24 to 37 km s\(^{-1}\)), indicates that, if any, there is very little dark matter in UCD galaxies. Indeed assuming UCDs are virialized structure, masses ranging from \(10^7\) to \(10^8\) M\(_\odot\) are found (Drinkwater et al. 2003). The corresponding mass-to-light ratio varies from 2 to 4 in solar units, fully consistent with the expectation for an old stellar population without significant amount of dark matter.

In the literature two different scenarios have been proposed to explain why UCDs show no mass discrepancy. One possibility is that UCDs are giant globular clusters (Mieske et al. 2002), possibly the result of the merging of the giant stellar clusters created during periods of strong galaxy interaction (Fellhauer and Kroupa 2002), like the one observed in the “Antennae” system (e.g., Whitmore et al. 1999). The other possibility is suggested by the fact that UCDs luminosity and size match well the one of the nucleus of dwarf galaxies. It is therefore possible that UCD galaxies are the remnant of normal nucleated dwarf galaxies that have lost their external halo and dark matter, because of strong and repeated interaction with other galaxies. This latter scenario is referred to as galaxy threshing (Gregg et al. 2003).

To these two possibilities to explain the low M/L ratio of UCDs, I would add a third one: Modified Newtonian Dynamics (MOND; Milgrom 1983). MOND posits the breakdown of Newtonian dynamics when the acceleration of gravity goes below \(a_0 = 1.2 \times 10^{-8}\) cm s\(^{-2}\). A hypothesis based on the fact that mass discrepancies are observed in stellar systems when and only when the internal acceleration of gravity falls below \(a_0\) (e.g., Binney 2004). Despite many attempts, MOND resisted stubbornly to be falsified as an alternative to cold dark matter (CDM; e.g. Sanders, McGaugh 2002) and succeeds in explaining the properties of an increasingly large number of stellar systems without invoking the presence of non-baryonic dark matter. Now that a Lorentz covariant theory for MOND exists (Bekenstein 2004), there is an obvious need to search for more sites where predictions of MOND and CDM could clash. Ultra-Compact Dwarf galaxies may represent one of them.

2 MOND PREDICTION FOR UCD GALAXIES
Considering the most extreme case of \(M_B = -11\), a radius of 100 pc, and M/L=2 in solar units, we see that even at the outer edge the acceleration of gravity is \(5 \times 10^{-8}\) cm s\(^{-2}\) > \(a_0\). According to MOND, then, UCDs are every-
where in Newtonian regime. The simple and at the same time strong prediction is that no non-baryonic dark matter is to be found in UCDs. Up to now, MOND is in full agreement with observations.

Within this framework, the reason why we do not observe a mass discrepancy is neither due to the particular evolutionary history of this galaxies, nor to the fact that UCDs can actually be giant globular clusters. It is solely due to the fact that they are in Newtonian regime and therefore should strictly obey Newtonian dynamics.

Based on this simple consideration, one has to conclude that UCDs provide a very good test-bench for MOND. It is sufficient to find a single UCD with an unquestionably large mass discrepancy to falsify the theory. Targeting stellar-like objects in the right range of luminosity with multi-object spectrographs will certainly allow in the near future the discovery of many more of this galaxies. Indeed, a number of UCD in Virgo has been already found (Drinkwater et al. 2004), though their velocity dispersion is still unknown. Once a seizable sample will be available, beside the interest of better investigate the properties of UCDs, we will be able to put strong constraints on MOND.

Moreover, in the case some intermediate UCD galaxies will be found, i.e., objects with a small halo thus resembling a little more regular nucleated dwarf, MOND made another interesting prediction. If it will possible to trace their velocity dispersion profile sufficiently far away from the center, then a mass discrepancy will be observed as soon as internal acceleration of gravity below \( a_0 \) are probed. A similar behavior has been already observed in three galactic globular clusters (Scarpa, Marconi, and Gilmozzi 2003, 2004).

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