

A Test of Newton's Law of Gravity in the Weak Acceleration Regime

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1. Introduction

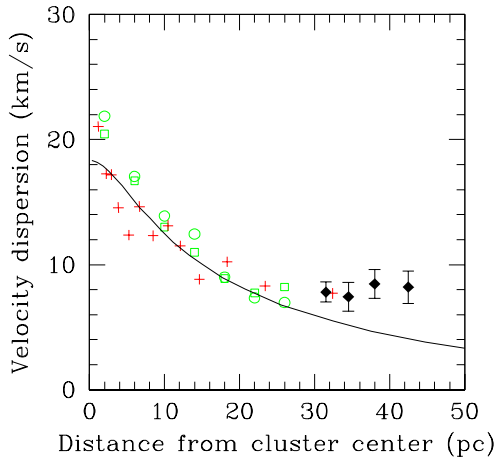
Newton's law of gravity is routinely used to describe galaxies, even though its validity has been fully verified only within the solar system, in regimes of acceleration orders of magnitude stronger than the ones typical of galaxies. Though we have plenty of reasons for trusting Newton's law also in these weak regimes, there are strong observational evidence that all spacecrafts in the periphery of the solar system are experiencing an anomalous, unexplained acceleration toward the sun (Anderson et al. 1998). Moreover, the modified Newtonian dynamics (MOND; Milgrom 1983, Sanders & McGaugh 2002), which posit a breakdown of Newton's law of gravity below few times $a_0 \sim 10^{-8} \text{ cm s}^{-2}$, succeeds in explaining many properties of galaxies and other astrophysical phenomena without invoking non-baryonic dark matter (DM).

Because of these empirical evidence, we decided to perform an experiment to test Newton's law of gravity. We focused on globular clusters (GC) because they are the smallest virialized structure believed to be DM free. This ensures GC's internal dynamics should follow precisely the prediction of Newton's law for any acceleration, in particular below a_0 . In the case a discrepancy would be found, then DM can not be invoked to explain it, and Newton's law would be falsified.

2. Results for a Pilot Experiment on ω Centauri

We studied the outskirts of the GC ω Cen, which was selected for having known internal proper motion (van Leeuwen et al. 2000) and because visible from Paranal. To reach gravitational acceleration below $10^{-7} \text{ cm s}^{-2}$, we have selected 91 stars from van Leeuwen et al. (2000) at distance $> 30 \text{ pc}$ from the center and membership probability $> 90\%$. Radial velocities with average accuracy of 0.8 km s^{-1} were subsequently obtained at the ESO Very Large Telescope (VLT) with UVES. Of the selected candidates, 75 were found to be cluster members.

Combining our data with data from literature we trace the velocity dispersion σ profile up to 45 pc from the center, finding σ remains large and basically constant at large radii (Fig. 1). As evident from Fig. 1, the cluster is isotropic so the use of radial velocity only to derive σ does not limit the generality of our result. The profile flattens out for $r > 25 \text{ pc}$, equivalent to an acceleration of gravity of $\sim 10^{-7} \text{ cm s}^{-2}$ (for cluster mass $4.2 \times 10^6 M_\odot$). This is comparable to the acceleration regime for which dark matter starts to be relevant in galaxies.



Velocity dispersion profile of ω Cen. Proper motion data (**Circles** and **Squares**; van Leeuwen et al. 2000) and radial velocities (**Crosses**; Meylan et al. 1995 up to 20 pc, last two points from Meylan & Mayor 1986) agree well showing the cluster is isotropic. The solid line is the best fit model to the radial velocity data as in Meylan et al. (1995) (their fig 1). Our velocity dispersion data (**Diamonds**) show the dispersion starts to be constant for $R > 25$ pc, where the acceleration falls below 10^{-7} cm s^{-2} .

The large σ can be the result of tidal heating, or can be due to a large number of binary stars in our sample. Alternatively, if ω Cen were a galaxy (Hilker & Richtler 2000), our result may indicate a substantial amount of DM survived all the tidal stripping that transformed the galaxy into the cluster we see today. Though none of this possibility can be ruled out by present data, all requires fine tuning of the relevant parameter to explain the flattening of the velocity dispersion profile. It is striking that ω Cen is hundreds of times smaller than a galaxy and still its dispersion profile mimics precisely the one observed in elliptical galaxies and explained invoking DM (Carollo et al. 1995).

Interestingly, for the GC Pal 13 a mass-to-light ratio $M/L \gtrsim 11$ has been reported (Meylan 2001). Such high M/L , unique among GCs, can be explained if Pal 13 is out of dynamical equilibrium. In view of the result just found for ω Cen, we suggest the large M/L is another manifestation of a breakdown of Newton's law. For $M/L = 3$ the acceleration of gravity is below 10^{-7} cm/s^2 all the way to the cluster center. It is therefore not surprisingly that Pal 13 appears dominated by DM.

As a whole, we believe our result for ω Cen, the one for Pal 13, and the anomalous acceleration experienced by spacecrafts in the solar system, all suggest a breakdown of Newton's law of gravity in the weak acceleration regime.

References

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