MOND over dark matter?

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The average orbital velocities of planets in the solar system vary as the inverse square root of distance from the Sun. Thus the Earth orbits at about 30 km/s, Mercury at 48 km/s and Pluto at a leisurely 4.7 km/s. This behaviour, an expression of Kepler's laws of planetary motion, is termed 'Keplerian'. It arises from Newtonian dynamics, including the inverse-square law of gravitational attraction, together with the fact that most of the mass in the solar system is concentrated very close to the centre in the Sun.

When mid-twentieth century astronomers first investigated galaxy rotations, they expected orbital velocities outside the nuclear bulge to decrease with distance from the centre in Keplerian fashion. Indeed the earliest attempts to obtain rotation curves (plots of orbital velocity against distance from the centre) for spiral galaxies, although subject to large measurement errors, produced results roughly consistent with this expectation. However during the 1970s Vera Rubin and colleagues used the Doppler shifts of spectral lines—mainly optical emission lines from clouds of ionized hydrogen and the 21-cm radio emission line from neutral hydrogen—to establish reliable rotation curves for numerous spiral galaxies.[1–3] The results were both surprising and remarkably consistent: rotation curves in the outer regions of galaxies did not fall with radius in Keplerian fashion. Instead they stayed roughly constant, or even rose slightly towards the outer edges of galaxies. An illustrative rotation curve is shown in Figure 1.

The mass discrepancy problem

This result may be viewed as a discrepancy between galaxy masses inferred dynamically and from their emitted light distributions—the 'mass discrepancy' problem. Once generally accepted, it was taken as evidence that galaxies were accompanied by very significant quantities of otherwise undetected or 'dark' matter distributed up to and often beyond, their visible boundaries.[4] This postulated dark matter is important in today's mainstream cosmology. Modern cosmology proposes a 'flat' inflationary big-bang universe in which the effective mass density of the universe consists of dark energy, dark matter and the more familiar visible matter (stars, gas, planets and the like), with the latter only contributing a few percent of the total. Galaxy formation is thought to have begun with density variations in the supposed distribution of dark matter in the early expanding universe. Not only have objects such as white dwarf stars, brown dwarfs, black holes and neutrinos been proposed to account for the dark matter, but also various exotic hypothetical objects including gravitinos, photinos, axions, magnetic monopoles, WIMPs and MACHOs.[5]

But, we ask, is all this really good science? To begin with, the presence of dark matter has recently been called into question in creationist[6,7] and in general astronomical literature.[8–11] The recent detection of faint white dwarf stars allegedly belonging to the Milky Way halo population was hailed as revealing a sample of the elusive dark matter.[12] However, these stars more probably belong to a thick galactic disk population.[13]

Not only this, but have alternative interpretations of the mass discrepancy problem been proposed and only rejected after careful investigation? The answer to this last question proves to be very interesting. As early as 1963 Finzi[14] suggested a distance-based modification of gravity to resolve the mass discrepancy problem for galaxy clusters, but this seems to have received little attention. Then in 1983 the Israeli physicist Moti Milgrom proposed[15] a modification of Newtonian dynamics, known as MOND, designed to reproduce the observed 'flat' galaxy rotation curves using only observed distributions of visible matter and reasonable

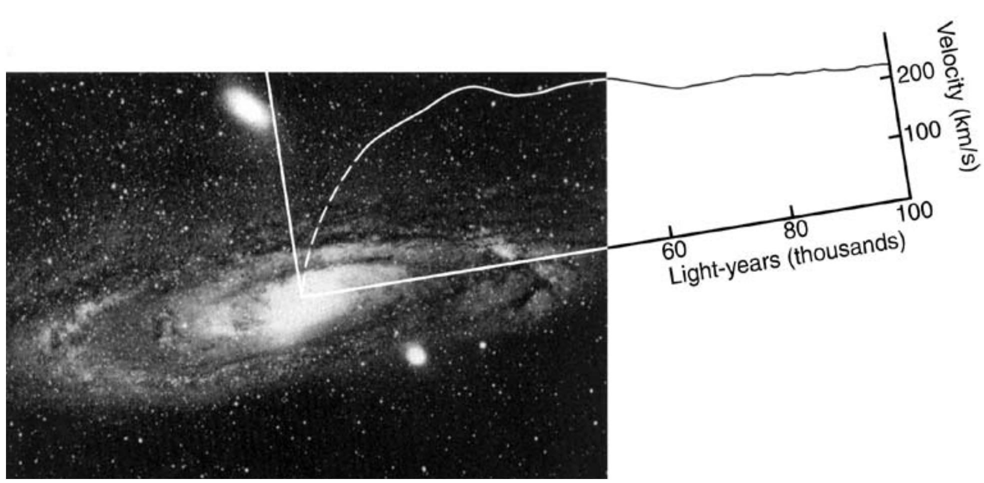

Figure 1. *Rotation curve of the galaxy M31 in Andromeda plotted to scale against an optical photograph of the galaxy. Measurements were based on 21-cm radio emission from neutral hydrogen, which extends beyond the visible edge of the galaxy (this hydrogen is not counted in its presumed 'dark matter' inventory) (From Begelman and Rees).*[41]

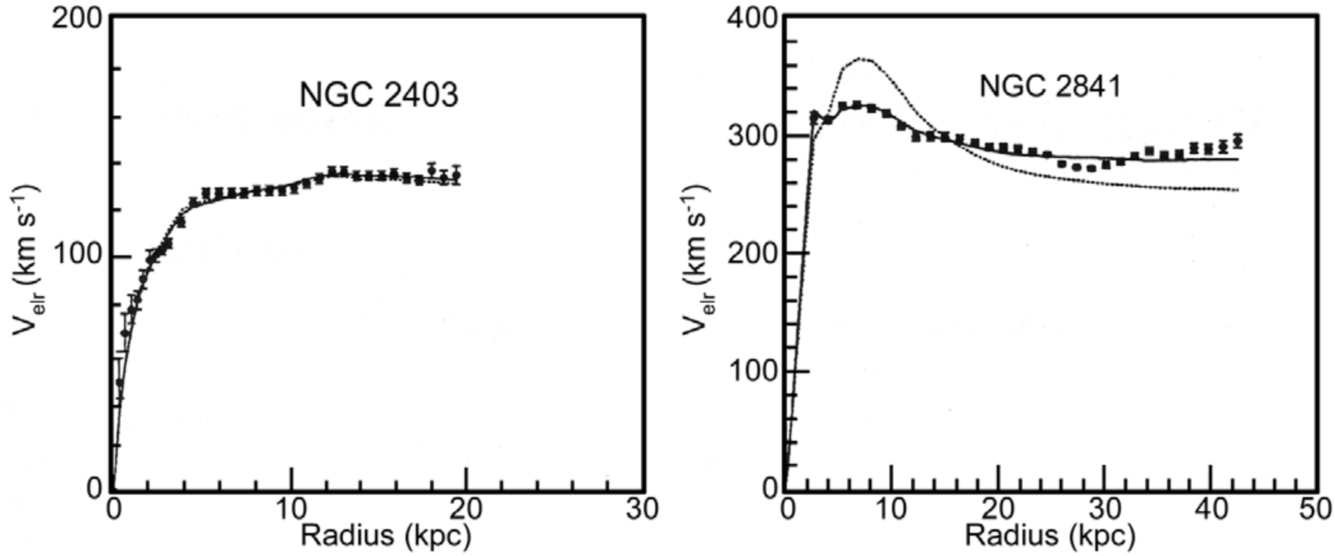

Figure 2. *MOND fits to the rotation curves of sample galaxies from Ref. 28 using the value of a_0 given in the text. Dotted curves are one-parameter fits (M/L) while solid curves are two-parameter fits (M/L and distance).*

assumptions about mass/light ratios as input data. MOND applies at the very low accelerations which occur in the outer regions of spiral galaxies and in galaxy groups; accelerations are higher in the familiar (inner) region of the solar system. The Newtonian equation for a particle moving under gravity, viz

$$a = GM / r^2$$

(where a is the radial acceleration, G the universal gravitational constant, M the attracting mass and r the distance from the centre of mass), becomes

$$a^2 / a_0 = GM / r^2$$

where a_0 is the critical acceleration level below which MOND applies.[16] This can be viewed as either a modification of the law of inertia or of the law of gravity,[15] the latter being preferred because it involves a less radical modification of recognised physics.[17] Indeed there are still several mysteries surrounding gravity, for example possible shielding of the Sun's gravity by the Moon during solar eclipses[18,19] and general relativistic 'frame dragging', shortly to be investigated by the Gravity Probe B experiment.[20] Van Flandern[21] has reviewed some of the questionable aspects of our understanding of gravity.

Wright, Disney and Thompson[22] have suggested a modified (inverse linear) law of gravity beyond a certain distance scale to explain the mass discrepancy problem in galaxies, galaxy clusters and superclusters. Liboff[23] and others have considered similar possibilities too, but McGaugh and de Blok[24] insist that **acceleration**, not distance, is the decisive factor. This is because the mass discrepancy is less severe for high surface brightness (HSB) galaxies than for smaller, low surface brightness (LSB) galaxies where centripetal accelerations fall to extremely low values of order 10^{-11} ms^{-2}.

By using MOND for a single universal value of a_0, i.e. 1.2×10^{-10} ms^{-2} (about 100 billion times smaller than the acceleration due to gravity at the Earth's surface), the rotation curves of many galaxies can be reproduced without assuming the presence of appreciable quantities of dark matter![25]

Testing MOND predictions

When Milgrom's ideas were first published, sufficient rotation curves of HSB galaxies were already established that MOND calculations could scarcely be regarded as predictions; they could rather be viewed as parameter-fitting exercises for a_0. Since then, however, rotation curves for LSB galaxies have become available which provide a more stringent test of MOND than the earlier data. The results are remarkably good.[24,26] Furthermore, MOND naturally predicts the Tully-Fisher relation for spiral galaxies,[27] the observed correlation between rotation velocities and mass (originally expressed in terms of neutral hydrogen line widths and absolute luminosity) which is often used as a distance indicator. A detailed comparison between MOND and 'Dark Matter' predictions for a sample of spiral galaxies with accurately measured rotation curves[28] concluded that MOND provided the best available description. This was despite 'Dark Matter' being allowed three adjustable model parameters, while in most cases MOND was only allowed one, the mass/light ratio for each galaxy. Figure 2 shows sample MOND fits to measured rotation curves from this paper.

Galaxy rotation is not the only way of testing theories of gravity or inertia. Astronomer Stacy McGaugh (University of Maryland) has set up a MOND web site,[29] which includes a page[30] listing itemized comparisons of the predictions of MOND and 'Dark Matter'. These deal with the dynamics of individual elliptical and spiral galaxies of various sizes, motion within galaxy clusters, large scale structure in the universe, gravitational lensing and indeed the spatial structure of the cosmic microwave background radiation. Frequently MOND gives clear predictions where the dark matter hypothesis either has serious fine-tuning problems or gives no prediction. In most cases MOND predictions match the data very well, though sometimes the data is inadequate to provide a clear test. Rubin[31] briefly alludes to X-ray observations[32,33] which apparently discredit MOND predictions for galaxy clusters. However McGaugh and de Blok[24] point out that this data is subject to major uncertainties which preclude a critical test, and that the dark matter interpretation is also problematical, and Sanders[34] has shown how MOND neatly predicts the mass-temperature relationship for gas-rich galaxy clusters. Some authors[15,17,35] have noted that the MOND acceleration constant a_0 is of the same order as cH_0, where c is the speed of light and H_0 the Hubble constant, thus hinting at its possible cosmological significance.

Gravitational lensing appears to be the least promising area for MOND. However, this is essentially a GR (general relativistic) phenomenon, and MOND has yet to be formulated in GR terms. Thus Binney[36] has commented that MOND cannot fairly be tested against such effects. Milgrom[35] has recently considered its possible origin in vacuum effects, and Sanders[37] has shown how scalar-tensor theories can be constructed which reproduce many MOND predictions. The main objection to MOND is thus summed up by Livio: 'Milgrom's conjecture has not gained many supporters, primarily because it has never been developed into a truly complete theory.'[38] Future developments could change this.

Why is MOND unpopular?

The answer to our question regarding the interpretation of the mass discrepancy problem is, therefore, that MOND is a very successful, albeit purely phenomenological, alternative to dark matter. It is strongly favoured by Occam's razor in that it makes clear predictions and is therefore falsifiable, but remains unfalsified. However, rather than being carefully investigated by experts in the field, it has largely been ignored. Those who have commented tend to dismiss it summarily. Thus Rubin says: 'this possibility must remain as a last resort'[39] and 'Most astronomers prefer to accept a universe filled with dark matter rather than to alter Newtonian gravitational theory.'[40] Thus it seems that MOND has been ignored not for objective scientific reasons but largely because it implies the existence of much less dark matter than is required by the currently dominant flat, accelerating-universe cosmology which Livio[5] regards as so beautiful that it 'has' to be true.

What interest do creationists have in MOND, a purely mechanistic theory, which was not developed with origins in mind? First, creationist astronomers and cosmologists should be aware of developments which, at least indirectly, impinge on our understanding of the astronomical data relevant to creation. Moreover the remarkably successful predictions of MOND could be pointing to the need for fundamentally new physics at a time when we are hearing that human understanding of the physical universe is nearly complete! MOND exposes deep cracks behind the self-confident façade of modern uniformitarian cosmology and thus reminds us of the fallibility of scientific paradigms, especially when they have been developed in ignorance of the Creator. Recall Isaiah 29:14, which says of those who ignore God: '… the wisdom of the wise will perish, the intelligence of the intelligent will vanish.'

References

1. Rubin, V.C., *Bright Galaxies Dark Matters*, Springer-Verlag Inc., New York, 1996.
2. Rubin, V.C., Ford, W.K., Jr. and Thonnard, N., Rotational properties of 21 Sc galaxies with a large range of luminosities and radii, from NCG 4605 (R = 4 kpc) to UGC 2885 (R = 122 kpc), *Ap. J.* **238**:471–487, 1980.
3. Rubin, V.C., Burstein, D., Ford, W.K., Jr. and Thonnard, N., Rotation velocities of 16 Sa galaxies and a comparison of Sa, Sb, and Sc rotation properties, *Ap. J.* **289**:81–104, 1985.
4. Dark matter had also been inferred from the large velocity dispersions observed in galaxy clusters by Zwicky and Oort in the 1930s.
5. Livio, M., *The Accelerating Universe,* John Wiley & Sons, Inc., New York, 2000.
6. Oard, M. and Sarfati, J., No dark matter found in the Milky Way galaxy, *CEN Tech. J.* **13**(1): 3–4, 1999.
7. DeYoung, D.B., Dark matter, *CRSQ* **36**(4): 177–182, 2000.
8. Lucentini, J.A., Handle on dark matter? *Sky and Telescope* **103**(1):16–17, (News Notes, January 2002), 2002.
9. Olling, R.P. and Merrifield, M.R., Luminous and dark matter in the Milky Way, *MNRAS* **326**(1):164–180, 2001.
10. Binney, J.J. and Evans, N.W., Cuspy dark matter haloes and the galaxy, *MNRAS* **327**(2), pp. L27–L31, 2001.
11. Governato, F., Moore, B., Cen, R., Stadel, J., Lake, G. and Quinn, T., The Local Group as a Test of cosmological models, *New Astronomy* **2**(2):91–106, 1997.
12. Oppenheimer, B.R., Hambly, N.C., Digby, A.P., Hodgkin, S.T. and Saumon, D., Direct detection of galactic halo dark matter, *Science* **292**(5517):698–702, 2001.
13. Reid, I.N., Sahu, K.C. and Hawley, S.L., High-velocity white dwarfs: thick disk, not dark matter, *Ap. J.* **559**(2):942–947, 2001.
14. Finzi, A., On the validity of Newton's Law at a long distance, *MNRAS* **127**:21–30, 1963.
15. Milgrom, M., A modification of the Newtonian dynamics as a possible alternative to the hidden mass hypothesis, *Ap. J.* **270**:365–370, A modification of the Newtonian dynamics: implications for galaxies, 371–383 and A modification of the Newtonian dynamics: implications for galaxy systems, 384–389 (referred to as papers I, II and III where necessary), 1983.
16. There is a 'transition range' of accelerations characterized by $a \sim a_0$ where an interpolation function, not prescribed *a priori*, is required to match the conventional and MOND regimes, but MOND predictions do not seem to depend critically on the form chosen for this function.
17. Bertin, G., *Dynamics of Galaxies*, Cambridge University Press, 2000.
18. Wang, Q.S., Yang, X.S., Wu, C.Z., Guo, H.G., Liu, H.C. and Hua, C.C., Precise measurements of gravity variations during a total solar eclipse, *Phys. Rev. D* **62**:041101, (pp. 1–3), 2000.
19. Unnikrishnan, C.S., Mohapatra, A.K. and Gillies, G.T., Anomalous gravity data during the 1997 total solar eclipse do not support the hypothesis of gravitational shielding, *Phys. Rev. D* **63**:062002, (pp. 1–4), 2001.
20. See <einstein.stanford.edu/>, 16 July 2002.
21. <www.metaresearch.org/cosmology/gravity/

possiblenewpropertiesofgravity.asp>, 16 July 2002; see also Van Flandern, T., Possible new properties of gravity *Ap&SS* **244**: 249–262, 1996.

22. Wright, A.E., Disney, M.J. and Thompson, R.C., Universal gravity: was Newton right? *Proc. ASA* **8**(4):334–338, 1990.
23. Liboff, R.L., Generalized force law and hidden mass, *Ap. J.* **397**:L71–L73, 1992.
24. McGaugh, S.S. and de Blok, W.J.G., Testing the hypothesis of modified dynamics with low surface brightness galaxies and other evidence, *Ap. J.* **499**:66–81, 1998.
25. Sanders, R.H. and Verheijen, M.A.W., Rotation curves of Ursa Major galaxies in the context of modified Newtonian dynamics, *Ap. J.* **503**:97–, 1998.
26. de Blok, W.J.G. and McGaugh, S.S., Testing modified Newtonian dynamics with low surface brightness galaxies: rotation curve fits, *Ap. J.* **508**:132–140, 1998.
27. Tully, R.B. and Fisher, J.R., A New method of determining distances to galaxies, *Astr. Ap.* **54**: 661–673, 1977.
28. Begeman, K.G., Broeils, A.H. and Sanders, R.H., Extended rotation curves of spiral galaxies: dark haloes and modified dynamics, *MNRAS* **249**:523–537, 1991.
29. <www.astro.umd.edu/~ssm/mond/>, 7 June 2002.
30. <www.astro.umd.edu/~ssm/mond/mondvsDM.html>, 7 June 2002.
31. Rubin, Ref. 1, pp. 137, 138.
32. Buote, D.A. and Canizares, C.R., X-ray constraints on the shape of the dark matter in five Abell clusters, *Ap. J.* **400**(2):385–397, 1992.
33. Buote, D.A. and Canizares, C.R., Geometrical evidence for dark matter: X-ray constraints on the mass of the elliptical galaxy NGC 720, *Ap. J.* **427**(1):86–111, 1994.
34. Sanders, R.H., A Faber-Jackson relation for clusters of galaxies: implications for modified dynamics, *Astr. Ap.* **284**,L31–L34, 1994.
35. Milgrom, M., The modified dynamics as a vacuum effect, <arxiv.org/astro-ph/pdf/9805346>, 1999 (or *Phys. Lett. A* **253**:273–, 1999).
36. Binney, J.J., private communication, 2002.
37. Sanders, R.H., A Stratified Framework for Scalar-Tensor Theories of Modified Dynamics, *Ap. J.* **480**:492–, 1997.
38. Livio, Ref. 5, p. 90.
39. Rubin, Ref. 1, p. 115.
40. Rubin, Ref. 1, p. 125.
41. Begelman, M.C. and Rees, M.J., *Gravity's Fatal Attraction: Black Holes in the Universe*, Scientific American Library, W.H. Freeman and Co., ISSN 1040-3213: no. 58, 1996.

Greenland ice cores: implicit evidence for catastrophic deposition

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A number of cores have been drilled into the Greenland ice cap (Figure 1). Two of them, GRIP (Greenland Ice Project) and GISP2 (Greenland Ice Sheet Project) are only 28 km apart, and have been discussed in terms of their overall characteristics. Notably, the two cores disagree strongly in their bottom parts, which, according to conventional dating, are said to represent a time period beginning a few tens of thousands of years ago to about 250,000 years ago.[1] This article complements Oard's[1] studies by focussing on the numerous discrepancies that occur within the top of the cores, representing the most recent 13,500 alleged years, as opposed to the bottom parts of the core that represent earlier periods of time. It draws on recently published research,[2] which attempted to reconcile the two ice-core chronologies over that period. In particular, this paper examines the numerous difficulties in correlating these cores using 'annual' counted layers, sulfate-aerosol horizons, and the variation in oxygen isotopes. The variance in one core must be subject to *ad hoc* contractions and expansions (i.e. 'accordioned') in order to force it to fit the variance of other core. The lack of close correspondence between the two cores, especially in large segments (blocs), in spite of their geographic proximity, favours a catastrophic storm-dominated accumulation of the water material in the Greenland ice cap.

Non-annual layers

A profusion of (usually) visually distinctive layers is visible in the ice cores due to different composition, crystal structure and colouring of the ice. The visual layers in the GISP2 core have now been counted back to allegedly 40,000 years BP (before the present), although it is acknowledged that there are constant, fine-scale counting uncertainties in the 1–2% range. There are, in addition, numerous short breaks due to core loss (usually <10 years), over the inferred period of 3,000–9,000 years BP,[2] in which the number of missing layers must be interpolated from the thickness of the lost core sections.

It has previously been documented that the layers present need not be annual as uniformitarians assume.[3] Indeed, this fact is unwittingly borne out in the latest study. There are a few centuries of sharp disagreement between the two cores at about the middle of the 13th millennium BP, during which the annual-layer assumption must be waived if a constant mutual $\delta^{18}O$ signal is to be supposed:

> '… then the problem is not missing core or other "block" data loss. Rather, the GRIP core lacks about half the annual layers throughout this interval, or the GISP2 ice contains many subannual structures which mimic annual bands, or the layers are in fact annual but one of the counts is erroneous.'[4]

Clearly, since the layers are not

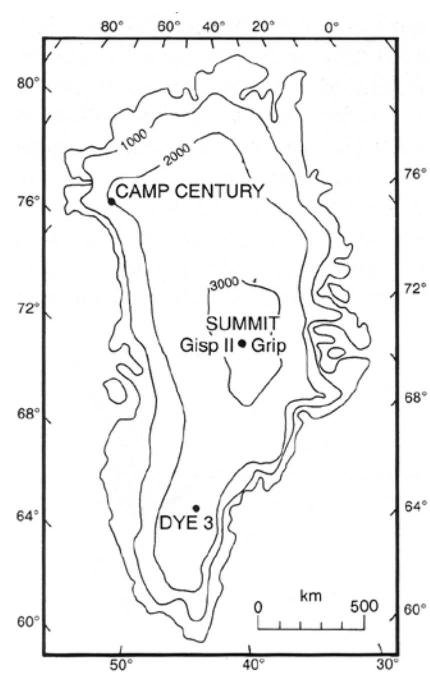

***Figure 1.** Location of the GRIP and GISP2 ice cores in central Greenland (after Oard).*[1]