

## 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 emis-

sion line from neutral hydrogen—to establish reliable rotation curves for numerous spiral galaxies.<sup>1-3</sup> 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.

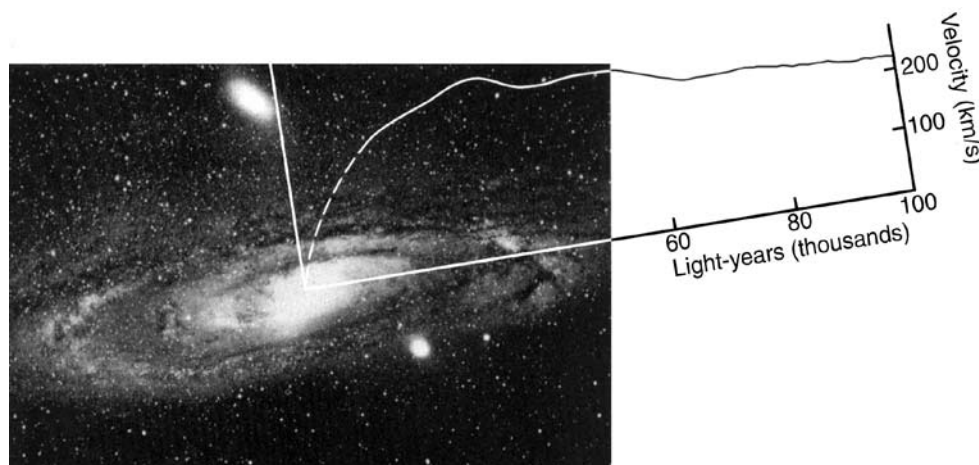
### The mass discrepancy problem

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.<sup>4</sup> 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

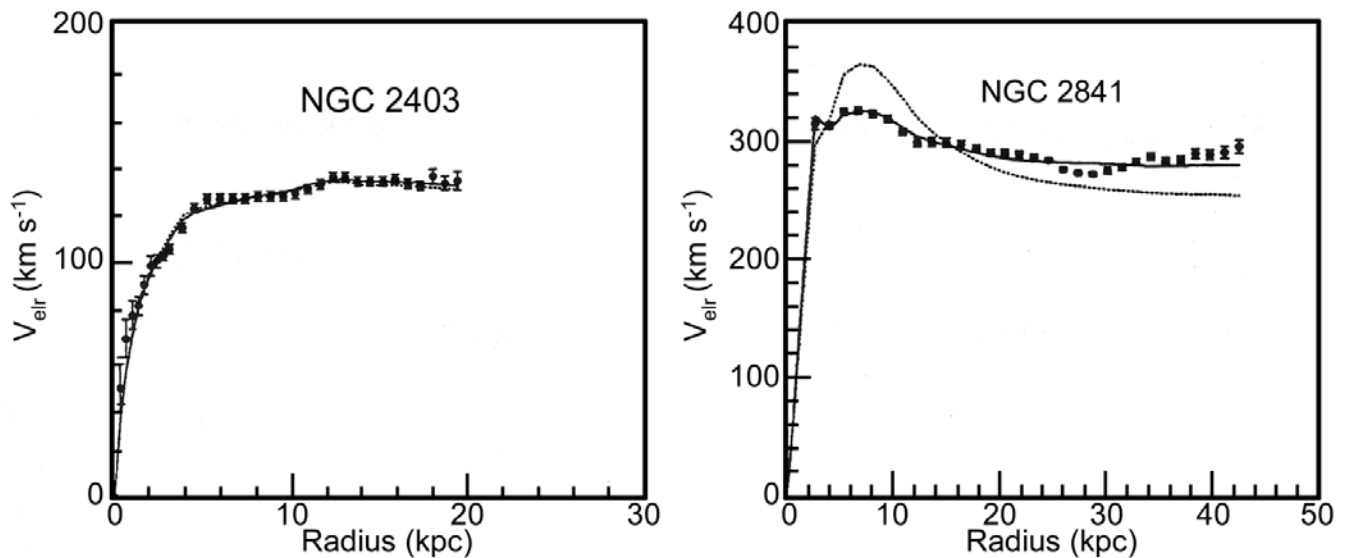
in the early expanding universe. Not only have objects such as white dwarf stars, brown dwarfs, black holes and neutrinos been proposed to account for the dark matter, but also various exotic hypothetical objects including gravitinos, photinos, axions, magnetic monopoles, WIMPs and MACHOs.<sup>5</sup>

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<sup>6,7</sup> and in general astronomical literature.<sup>8-11</sup> 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.<sup>12</sup> However, these stars more probably belong to a thick galactic disk population.<sup>13</sup>

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<sup>14</sup> 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<sup>15</sup> 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).<sup>41</sup>



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

Wright, Disney and Thompson<sup>22</sup> 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<sup>23</sup> and others have considered similar possibilities too, but McGaugh and de Blok<sup>24</sup> 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  $10^{-11} \text{ ms}^{-2}$ .

By using MOND for a single universal value of  $a_0$ , i.e.  $1.2 \times 10^{-10} \text{ ms}^{-2}$  (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!<sup>25</sup>

### 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.<sup>24,26</sup> Furthermore, MOND naturally predicts the Tully-Fisher relation for spiral galaxies,<sup>27</sup> 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<sup>28</sup> 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,<sup>29</sup> which includes a page<sup>30</sup> 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<sup>31</sup> briefly alludes to X-ray observations<sup>32,33</sup> which apparently discredit MOND predictions for galaxy clusters. However McGaugh and de Blok<sup>24</sup> 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<sup>34</sup> has shown how MOND neatly predicts the mass-temperature relationship for gas-rich galaxy clusters. Some authors<sup>15,17,35</sup> 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<sup>36</sup> has commented that MOND cannot fairly be tested against such effects. Milgrom<sup>35</sup> has recently considered its possible origin in vacuum effects, and Sanders<sup>37</sup> 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.'<sup>38</sup> 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'<sup>39</sup> and 'Most astronomers prefer to accept a universe filled with dark matter rather than to alter Newtonian gravitational theory.'<sup>40</sup> 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<sup>5</sup> 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.'

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## 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.<sup>1</sup> This article complements Oard's<sup>1</sup> 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,<sup>2</sup> 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,<sup>2</sup> 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.<sup>3</sup> 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 13<sup>th</sup> millennium BP, during which the annual-layer assumption must be waived if a constant mutual  $\delta^{18}\text{O}$  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.'<sup>4</sup>

Clearly, since the layers are not

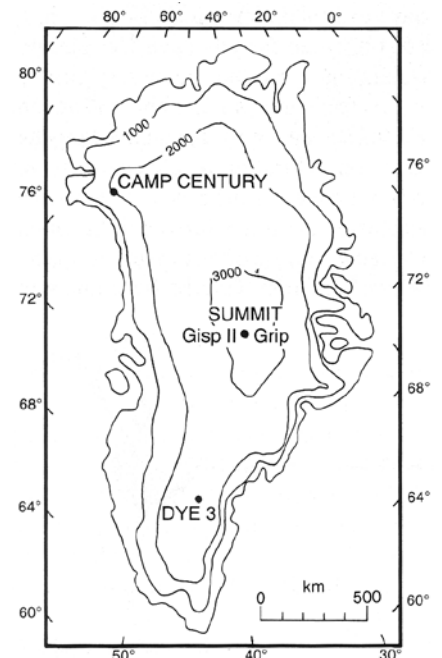


Figure 1. Location of the GRIP and GISP2 ice cores in central Greenland (after Oard).<sup>1</sup>