MOND and Observer Physics: Spiral Galaxies

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MOND is able to match the observed rotational curve data for many spiral galaxies quite well, but lacks a coherent theory to explain why the formula works the way it does. Observer Physics proposes an alternative that supports the MOND hypothesis by a logical extension of Newton's formula that takes into account observer viewpoint. This preliminary discussion only considers galaxies. Examples comparing the formula's predictions to the data include DDO 154, UGC 9242, NGC 1560, F563-1, NGC 2403, UGC 128, and M33.

When astronomers total up the amount of matter they see in galaxies, galactic clusters and other large formations, they find that there is not enough mass to account for the observed dynamics according to the usual application of Newton's gravitational formula. Even if we assume that there are dust particles and debris, and planets, and burned out stars, and so forth that can not be seen, there still does not seem to be enough matter to fit the dynamic behavior of these large-scale bodies. Therefore many astrophysicists believe that galaxies must have huge haloes of "dark matter" that our instruments can not detect, but which influence the dynamics of these galaxies in the manner that we observe. Some believe that exotic forms of matter such as WIMPs may be involved.

Israeli physicist, Mordehai Milgrom, has proposed (1983) Modified Newtonian Dynamics (MOND) as an alternative way to resolve the problem of galactic dynamics without resorting to a search for mysterious missing "dark" matter. His formula fits the data but does not say why. This problem in the rotational dynamics of large-scale physical systems remains one of the major difficulties in astrophysics and cosmology.

According to Newton's law as matter rotates in large celestial bodies at greater and greater distances from the gravitational center of mass of the system, it would seem that the gravitational force gets weaker, so the centripetal acceleration effect gets correspondingly weaker. Yet the far flung bodies in galaxies or other large systems move as if there were a much stronger gravitational influence than appears warranted by the observed mass in the central region that governs them.

Milgrom proposes a constant (ao) with the dimensions of acceleration that modifies the dynamical equations of Newton and describes these motions when the Newtonian acceleration falls below a certain threshold. Milgrom modifies Newton's gravitational equation by boosting the acceleration effects for distantly separated objects as follows.

* a = M G r^-2. (Newton)
* a^2 / ao = M G r^-2. (Milgrom)

These two can be written together:

* m (a / ao) a = M G r^-2 = aN.

Here (aN) represents the Newtonian acceleration. The expression [m (x)] satisfies [m (x)] ~~ 1 when x >> 1, and satisfies [m (x)] ~~ x when x << 1.

When the acceleration falls below the threshold (a << ao), Milgrom uses his constant to boost the gravitational effect. When (a >> ao), then systems follow Newton' s law. One key result is that bodies far from the mass center of a galaxy attain an orbital speed that is independent of the radius and proportional only to the fourth root of the total baryonic mass of the galaxy (the Tully-Fisher relation). Milgrom took the notion of asymptotic flatness of galactic rotational curves as axiomatic when framing his theory.

Milgrom estimates the value of (ao) to be

* ao = 10^-10 m / s^2.

The MOND constant relation appears to fit the data in most cases, especially fitting the well-studied disc galaxies. The main exceptions seem to be the cores of rich x-ray galactic clusters, where there is still a considerable discrepancy from his formula. In such cases Milgrom believes, and reasonably so, that there must be additional dark matter to make up the difference.

Milgrom' s procedure deals with low acceleration conditions. It does not integrate with relativity or quantum mechanics, breaks down entirely in the presence of black holes, and has not been integrated with the cosmology of the entire universe and its evolution, although there are some correlations emerging with the cosmic background radiation data.

Milgrom admits that his hypothesis is weak in that it lacks a theoretical foundation and does not work in the extreme ranges of physics. He sees it as a patch to get the observations to fit the equations. He can not say for sure why there should be a constant, or why it should have the value it has. One suggestion is that the MOND approach harkens back to Mach' s principle, the idea that "local" inertial gravitational effects are influenced by the global totality of mass in the universe.

The intergalactic distances are so great and the rate of falling off for the gravitational force so great that Mach' s principle seems improbable as a factor governing inertial effects at the cosmic level (but not necessarily at the level of internal galactic dynamics.)

Milgrom suspects that, if his constant is correct, it more likely requires an adjustment to inertia rather than to gravity. In observer physics we find that these two can not be separated, since they are conjugates of each other. Adjustment of inertia -- such as special relativity produced -- implies an adjustment to gravity.

Milgrom also speculates about possible influence from the vacuum state. The vacuum is Lorentz invariant with regard to constant speed, but may not be so with respect to acceleration. He even speculates on a possible macroscopic connection to the Casimir effect and the vacuum zero point.

Milgrom has a simple formula that fits the data, but no real coherent theory to back it up.

The key to galactic dynamics is the realization that the apparent value of the gravitational "mass" changes for particles inside a cloud. This principle would hold for galaxies as well as nebulae, and possibly in a very attenuated manner even for the whole universe. It would tend to show that the G-force between galactic participants would be strongest out in the wings of galaxies rather than close to the center.

Milgrom's estimate of $10^{-10}\ m/s^2$ for a(o) looks mighty close to the numerical value of (G) and leads right to the Tully-Fisher relation (which is where he got it).

* $Kx = (G)(ao) = 1\ m^4 s^{-4} kg^{-1} = V^4 / Mtot$.
* $a^2 / ao = M G r^{-2}$.
* $a^2 r^2 = M (G\ ao) = Kx\ M$.
* $a^2 r^2 = V^4 = Kx\ M$.

The problem with Milgrom's approach is that both his formula and the value of a(o) look arbitrary. Why should this shift from (a) to (a^2) suddenly take place at his (ao) threshhold? What causes the Tully-Fisher relation?

Why should matter at one distance from a center of mass (CM) behave in a fundamentally different way than matter at another distance? If it turns out that the "missing" dark matter doesn't really exist, what happens at Milgrom's a(o) acceleration threshold? Without some principle to explain why Newton's second law should suddenly shift gears in a galaxy, the idea sounds arbitrary. Adding such a rule when it may not be necessary complicates Newton's simple dynamics and may even threaten to modify our notions of geometry, given that general relativity is based on space/time geometry. We must justify such a complication.

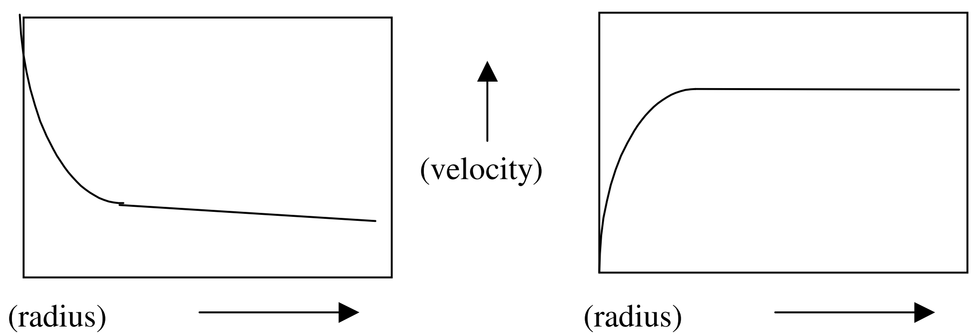
Newton predicts for the big circular orbits of stars in galaxies that:

* $A R^2 = G M$.
* $R V^2 = G M$.

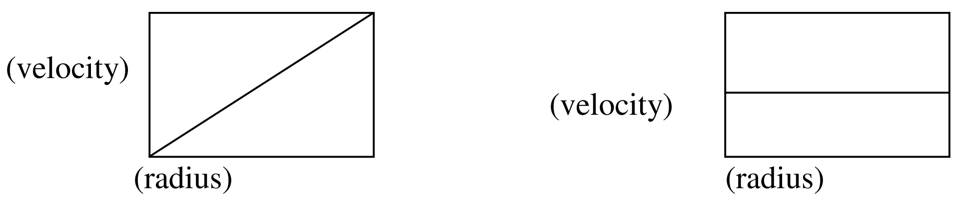
This means the acceleration drops off as the inverse square of the distance and the velocity increases as the inverse square root of the radius. To keep the velocity from dropping way down as we get far from the center we have to amplify the velocity somehow. Physicists figure they need around ten times the visible mass of a galaxy to hang around outside the galaxy as a "dark matter" halo in order to keep the galaxy holding together as it turns. That much normal matter should render the galaxy invisible. Because of the strong belief in Newton's correctness -- even though Newton had no idea of the existence of galaxies and other large cosmic formations when he made up his handy gravity law -- physicists strain at inventing all kinds of exotic hypothetical materials to account for the supposedly missing mass. Our analysis suggests that the problem is not that there is extra mass on the outside of a galaxy, but instead that there is cancellation of "mass" on the inside. Just like a static charge appears on a sphere's surface but there is no charge inside, so a galaxy that shows a strong gravitational influence from its outside, has diminishing net values of gravity on the inside due to relative equilibrium.

Galactic Rotation

The velocities of particles out in the "arms" of a large rotating system such as a galaxy or galactic cluster tend to be nearly independent of the radius. Velocities are also for the most part independent of the number of particles or the density unless the density becomes so low that the system no longer can function as a single entity or gets so high that black holes form. Below we compare a sketch of an average galactic rotation curve to a Keplerian curve.



Newton Curve (Keplerian Decline) Average Galactic Rotation Curve



Solid Bodies Velocity Independent of Radius

Only when the density is below the "cluster" density or when a particle is outside the cluster in "open space" does the relation between that particle and the cluster take on the normal Newtonian two-body behavior. Milgrom' s idea for a Modified Newtonian Dynamics (MOND) is correct. His only problem is that he needs a theoretical basis for his finding. Our analysis shows that a large cluster of particles with sufficient density (such as a galaxy) behaves internally as if the mass increases in linear relation to the radius. What actually happens is that the mutual attractions of the various component particles tend to cancel out in a state of gravitational equilibrium and this reduces the effective gravitational mass near the center and appears to increase it toward the periphery. A particle inside the cluster therefore tends to eventually behave as a member of the cluster and synchronizes its movements with the group so as to produce a trailing spiral in a coherently rotating galaxy. These dynamics do NOT follow Newton' s law for freely falling bodies. Particles in a cluster behave as if under the influence of "anti-gravity".

The rotation curves for galaxies look very much like mirror images of the usual

Newtonian rotation curve that shows the "Keplerian Decline". Newton' s relation is a hyperbolic equation. It describes the behavior of satellites that move in a highly diluted space outside a large gravity well. This is not the case for galaxies. They contain millions of solar systems all interacting like a huge gas cloud. The "internal" dynamics of galaxies are the **mirror image** of Newton' s "external" dynamics. We do not have to find huge amounts of invisible dark matter, nor do we need to do any major surgery on Newton' s law. We simply generalize it into an "internal" and "external" form. The difference is obtained by simply reversing the sign of any arbitrary component' s "internal velocity" and reversing the sign of the total galactic mass. The sign on the total mass reverses because the mass tends to pull "out" rather than "in" relative to component particles inside the cluster. The outward pull increases as an object nears the center of the galaxy. The sign on the "internal velocity" reverses because we set the outer edge of the cluster as the "zero point" boundary line for velocity -- that is, the asymptote for maximum "internal" velocity. The "external" law describes two objects moving externally relative to each other, so both velocities are positive. The two objects have equal relative speeds in opposite directions. The "internal" law deals with the case where the "satellite" component is "inside" the whole cluster, so the cluster' s relative velocity is positive, but the internal component' s relative velocity is negative. (Which is positive and which is negative is conventional so long as we are consistent in our relative viewpoints.)

Thus the speed of an isolated satellite outside, but close to a cluster of particles will be greatest near the cluster' s edge and then will drop off quickly as radial distance increases. It then fades off toward zero at greater radial distances. This is the Keplerian Decline. On the other hand, a star near the central core of a galaxy of many gravitationally interacting stars will have almost zero velocity. The velocity will pick up rapidly as the radial distance from the galaxy center grows, then it will level off as it nears an asymptotic velocity. Toward the outer regions of the galaxy the velocity will level off and seem independent of the radius and more likely influenced by other factors in the cluster' s makeup. This velocity is relative to an observer who is outside the galaxy. Unlike a planet that is some distance from the star it orbits, a star in a galaxy is **inside** the system.

Based on these observations we simply make a viewpoint shift and a tiny modification to Newton' s usual law to get the proper shape to the rotation curve.

*** Mcore G = Vsat Vcore R. (Newton's "External" Gravitation Law).**
*** - Mtot G = -Vcomp Vtot R. (Newton's "Internal" Anti-Gravitation Law).**

The first expression is Newton' s traditional relation. (Mcore) is the mass of the gravity well that anchors a satellite system. It may be a solar system or a planet with moons. (Vcore) is the velocity of the gravity well relative to an observer on the satellite. (Vsat) is the velocity of the satellite relative to an observer on the gravity well. In each case the "orbiting" object is "outside" the object it orbits. (R) represents the radial separation of the two bodies. Newton' s relation expresses the Keplerian Decline that characterizes such systems. The second expression is our modified version of Newton' s law for large-scale gravitationally structured clusters of objects. (Mtot) is the total mass of a large cluster formation such as a galaxy that has significant internal gravitational dynamics. We give it a negative sign because we are treating objects inside the cluster rather than outside as in the case of Newton' s traditional relation. (Vtot) is the velocity of the cluster at the position of the component object (e.g. star) as seen by an observer **outside the cluster**. (Vcomp) is the velocity of a given component (star) **inside** the cluster as seen by an observer **outside the cluster**. In the satellite case the velocities are equal and opposite in direction. In the component case the velocities are equal and identical in direction. Thus, if we keep the two velocity signs the same for the satellite case, then the two velocity signs must be opposite for the galaxy case.

The position of the observer relative to the system is vital to determining the orientation of the rotation curve. In the solar system situation observers see both objects as "outside" each other. However, in the galaxy system observers see the component as "inside" the galaxy, and the galaxy contains the component. Thus we conventionally set both velocities positive in the first case (solar system). But the component velocity is negative in the second case (galaxy). The mass is positive in the first case (solar system) because the net attraction to particles outside the gravity well is always inward toward the center of the gravity well. The mass is negative in the second case (galaxy) because the net attraction of the total mass of a galaxy is to draw central components outward away from the center of the gravity well.

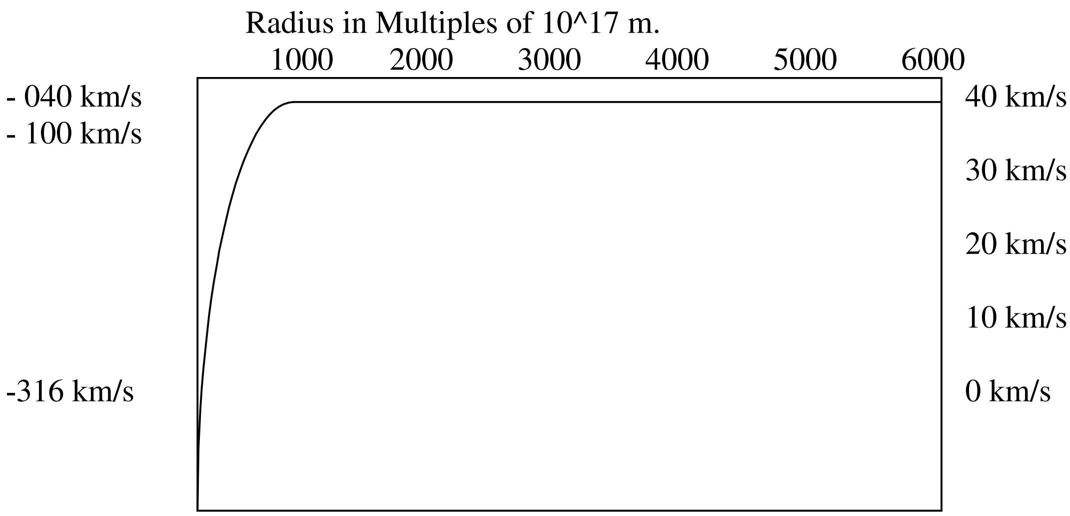
Let' s summarize our logical argument. **The density of material in a galaxy or other cluster causes the interacting gravitational effects of the various component masses to tend to cancel, depending on the radial distance from the center. A component in the cluster is surrounded by objects pulling it outward. The result is an "anti-gravity" effect inside large clusters of gravitationally interacting matter such as galaxies and galactic clusters. Newton' s Law is hyperbolic, and the rotation curves astronomers draw look hyperbolic and look very much like mirror images of the Keplerian Declines we see in Newtonian satellite systems. We get a mirror image by simply reversing a sign.**

Here is the rotation curve of a hypothetical galaxy calculated using our new formula. Let' s say we have a rotating spiral galaxy with a total visible mass of around 1.5x10^40 kg, or about 7.5x10^9 solar masses. Let' s say that the radius is about 6x10^20 m or around 6.3x10^4 light years. Let' s calculate the "negative" velocity at various radial distances from galactic center using our modified Newtonian formula and then convert that data into positive "real-world" velocities by simply re-calibrating the data and reading it backwards.

* (-Mtot) (G) = (1.5x10^40 kg) (6.67x10^-11 m^3/s^2 kg) = - 10^30 m^3/s^2.

* - V^2 R = -10^30 m^3/s^2. (We use this to calculate our outer rim velocity.)

*	**R**	**- V**	**Observed Relative Velocity (+V)**
	10^17 m	-3.16x10^6 m/s	0 m/s (approximate)
	10^18 m	-10^6 m/s	<10 km/2
	10^19 m	- 3.162x10^5 m/s	30 km/s
	5x10^19 m	- 1.4x10^5 m/s	36.2 km/s
	1x10^20 m	- 10^5 m/s	38 km/s
	1.5x10^20 m	- 8.16x10^4 m/s	
	2x10^20 m	- 7x10^4 m/s	38.5 km/s (nears asymptote)
	2.5x10^20 m	- 6.3x10^4 m/s	
	3x10^20 m	- 5.8x10^4 m/s	39 km/s
	4x10^20 m	- 5x10^4 m/s	39.8 km/s
	5x10^20 m	- 4.5x10^4 m/s	39.9 km/s
	6x10^20 m	- 4x10^4 m/s	40 km/s



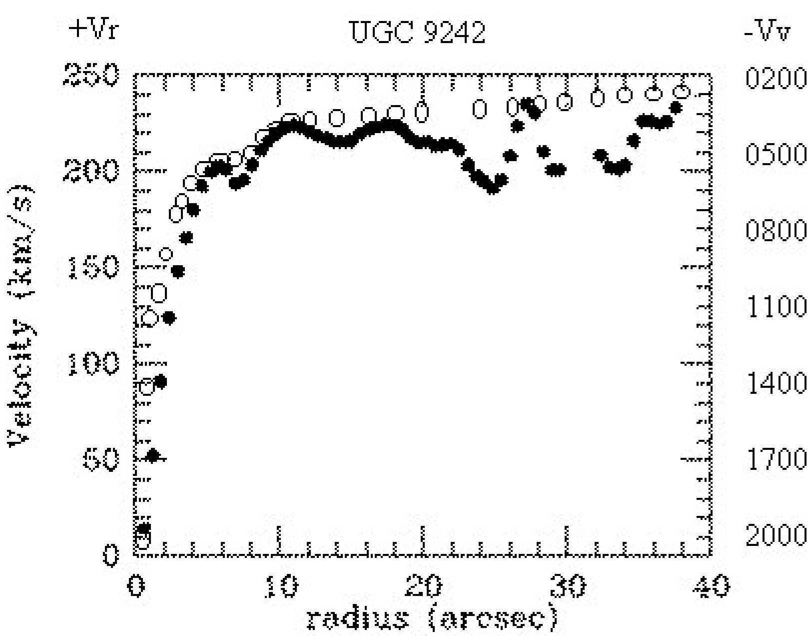
This simplified hypothetical data clearly shows the leveling off toward an asymptote as the radius increases. What happens as the radius decreases? The "negative" velocity value grows very quickly (i.e. drops off quickly toward a real world "zero" velocity.) But it moves into relativistic "negative" velocities as it approaches -10^7 m/s or higher. At smaller radial distances the relativistic shift goes up very rapidly. It doesn' t matter whether the velocities are positive or negative when it comes to the relativistic effects. Nor does the mass matter. The only thing that matters here is the value of (-v).

* [M1 (1 - v^2 / c^2)^1/2= Mo.] (Einstein' s relativistic shift of mass.)

This tells us roughly where the velocity cutoff is. Below a certain radial distance from the center the relativistic inertial resistance of a body to further negative acceleration will rapidly increase until it reaches an equilibrium point and stabilizes. This corresponds to "zero" velocity inside the galactic bulge core area. A black hole core would show orbital velocity degenerating into rotational velocity. Clearly the region R <= 10^16 m will correspond to approximately zero effective velocity for any component. Depending on actual observed maximum velocities we will know where along the relativistic curve the cutoff point lies. Velocity data from near the core of a galaxy tends to have a large smear factor. Speeds are getting quite slow, and density is higher. But we know for sure it will never reach -3x10^8 m/s, and will fall somewhere between -10^6 m/s and -3x10^8 m/s. This tells us the range of velocity for the system' s internal dynamics. Running our velocities backwards from the cutoff at zero to the periphery velocity that is known, we see a range. Given the cutoff I chose for the example, it goes from almost 0 m/s in the central region to around 40 km/s near the periphery. With the level of resolution for current equipment, anything from radial distance 10^19 m on out to 6x10^20 (and beyond if the system is larger) will seem to go at about the same velocity subject to local variations in structure.

With this simple theoretical framework we should now be able to work out the details of large-scale dynamics, filling in the variations based on individual cases. We thus settle one of the major headaches in modern cosmology. At least this aspect of the universe is OK after all, and we can stop fretting about the huge mass of missing Dark Matter.

Now let' s look at some examples of data taken from the observation of real galaxies. Our first example is the thin galaxy, UGC 9242.



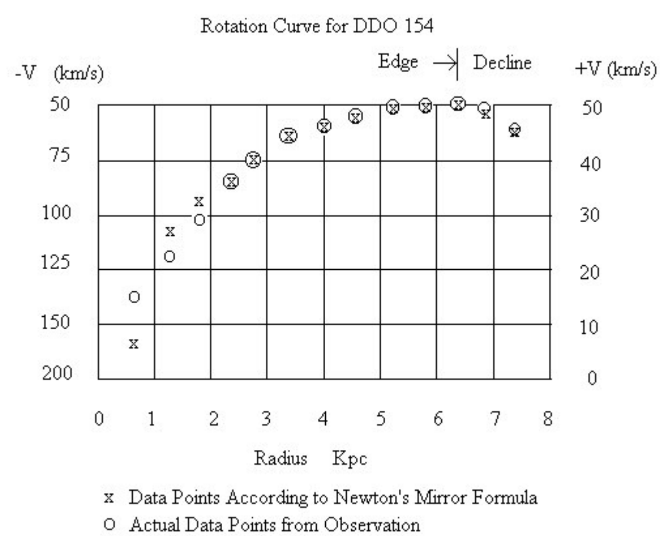
The above chart shows rotation curve data from galaxy UGC 9242 with an average peripheral velocity in the neighborhood of 230 km/s. The radius is measured on the chart in arcsecs from 0 to 40. Let' s see how well this data relates to our Newtonian formula. We' ll use for the galaxy rim the values R = 38 " andVv = -230 km/s. This gives us approximately (-Vv) (+Vv) R = (- 2x10^6 m^2/s^2) ("). The Newtonian Mirror Formula smooths out the curve ignoring local idiosyncrasies. This gives the smoother "negative" curve. Also, the negative curve (in hollow dots) is calibrated slightly higher so the two curves don' t overwrite each other. We label the negative curve' velocities "virtual" (Vv). We will call the real velocity that we observe (+Vr). The following is a table of approximate values. Black dots represent the observed data. Hollow dots show Newton' s ideal curve. (The chart and data were based on the Cornell University "Astronomy 201: Our Home in the Universe" web site example of a rotation curve by Martha Haynes and Stirling Churchman.)

*	R	+Vr	-Vv	(Velocity is in km/s.)
	38	230	230	
	36	225	235.7	
	35	225	239	
	32	210	250	
	30	200	258	
	29	210	262.6	
	28	230	267.26	
	27	235	272.16	
	26	220	277.35	
	25	180	282.84	
	24	190	288.6	
	20	215	316.2	
	18	225	333.33	
	16	225	353.55	
	14	215	377.96	
	12	220	408.25	
	11	225	426.4	
	10	220	447.2	
	09	215	471	
	08	210	500	
	07	190	534	
	06	200	577	
	05.5	205	603	
	05	200	632.45	
	04	190	707	
	03.5	180	755.93	
	03	165	816.5	
	02.5	150	894.43	
	02	125	1000	
	01.5	050	1154.7	
	01	050	1414	
	00.5	015	2000	
	(00	000	3x10^8)	(asymptotic values)

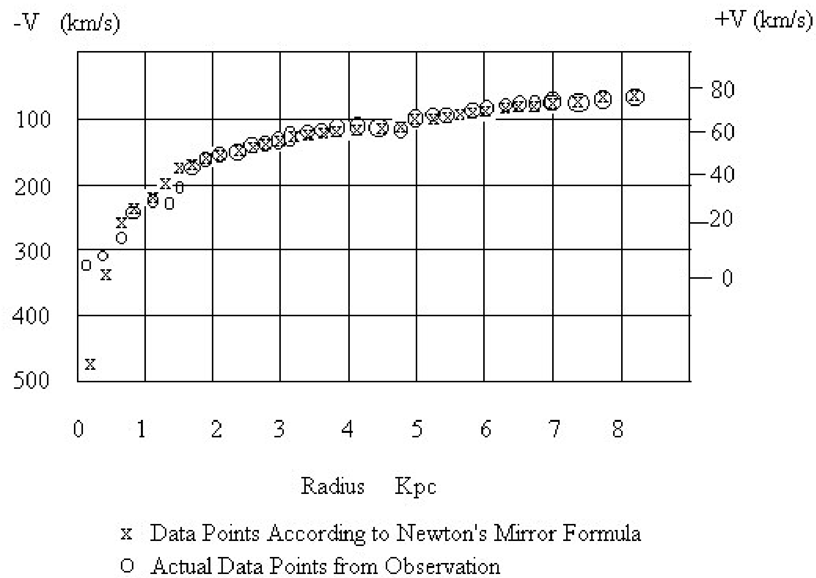
The next example we' ll look at is DDO 154, a test case with a very slow rotation. I estimated the data from a rotation curve plotted by Milgrom and Braun in "The Rotation Curve of DDO 154: A Particularly Acute Test of the Modified Dynamics." (Astrophysics Journal 334: 130-134, 1988 Nov. 1). Milgrom draws the curve showing the data compared with the curve his calculation generates and the curve predicted by Newton' s standard formula. Let' s see what our modified Newtonian Mirror Formula gives. The rotation curve, plotted in kiloparsecs vs km/s, shows a maximum peripheral velocity stable at around 50 km/s. Then it tapers off a bit at the very edge. This is due to material that is already drifting outside the "edge" and is starting to follow the Keplerian Decline. If we take 6.4 kpc as the edge, then we get G Mtot = 16000 kpc (km/s)^2. We simply flip the sign of Mtot to find that Newton' s Mirror law is a nice description of the rotation curve.

R (kpc)	V (km/s)	- V (km/s)	
0.00001	00	40000	
0.001	~0	4000	
0.1	~0	400	
0.6	15	163.3	
1.2	22	115.47	
1.8	29	94.28	
2.4	36	81.65	
2.8	40	75.59	
3.4	43	68.6	
4.0	46	63.245	
4.6	48	58.98	
5.2	50	55.47	
5.8	50	52.5	
6.4	50	50	(Outer Edge of Galaxy)

6.9	49	+48.15	(Keplerian Decline begins.)
7.4	47	+46.5	(Velocity becomes positive.)



Here is a Rotation Curve plotted for NGC 1560, a dwarf spiral. The data is based on A.H. Broeils, "The mass distribution of the dwarf spiral NGC 1560", Astron. Astrophys., 256, 19-32 (1992).



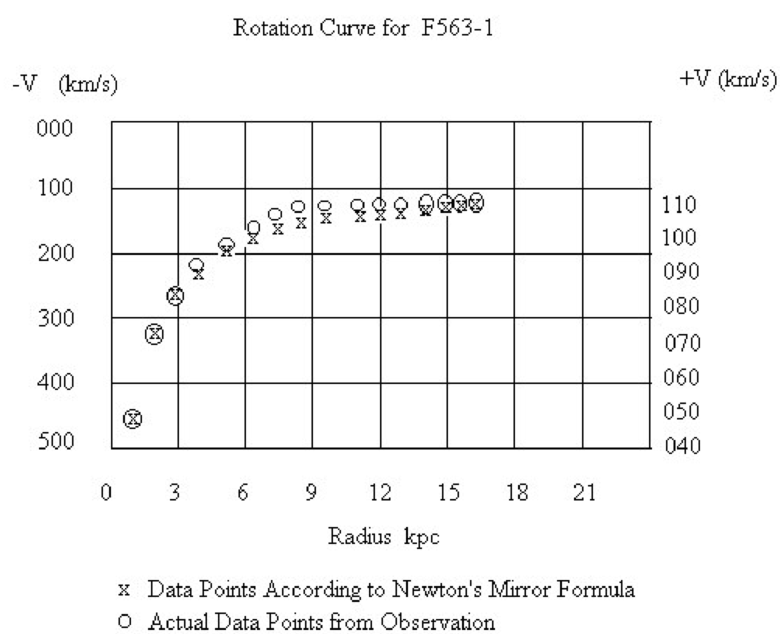
When we re-calibrate the negative plot into positive velocities there is a distortion at the low velocity range. This is partly due to greater smear factor in the data itself that occurs as measurements are taken closer to the core as you can see from the data below.

Here is a list of the data. The radial distances are in kiloparsecs, and I used Broeils' circular velocities corrected for asymmetric drift. The negative velocities are calculated from the product of the largest radius and the squared velocity at that radius (which is also maximum): 51,367.368 (kpc) km^2 / s^2.

R (kpc)	- V	+V	+/- Errors by least squares algorithm
0.22	485	05.0	7.5
0.4365	343	08.9	9.9
0.65475	280	14.5	6.3
0.873	242.57	26.4	5.6
1.09	216.96	28.9	5.7
1.3	198	27.8	2.3
1.53	183.365	31.8	3.2
1.746	171.522	42.8	2.1
1.96	161.7	48.2	1.6
2.18	153.4	48.4	1.3
2.4	146.3	50.6	1.0
2.619	140	53.5	1.0
2.837	134.55	57.2	1.3

3.055	129.658	59.1	1.5
3.274	125.26	59.8	1.6
3.492	121.28	60.3	1.6
3.71	117.667	60.7	1.6
3.9285	114.35	62.1	1.9
4.14675	111.298	63.6	1.6
4.365	108.48	62.0	1.6
4.583	105.866	60.5	1.4
4.8	103.4	60.3	1.5
5.019	101.158	63.8	1.3
5.238	99	66.1	1.3
5.456	97	67.7	1.2
5.6745	95.14	70.4	1.1
5.89	93.365	73.0	1.2
6.111	91.68	74.2	1.2
6.329	90	75.1	1.3
6.5475	88.574	75.2	1.2
6.76575	87.1336	76.3	1.3
6.984	85.76	77.2	1.4
7.42	83.2	76.9	1.5
7.857	80.856	77.5	2.0
8.2935	78.7	78.7	2.3

Our next example is F563-1. This data is from McGaugh and de Blok, "Testing the Hypothesis of Modified Dynamics with LSB Galaxies and Other Evidence," (Astrophys. J., 499: 66-81, 1998, May 20,) p. 73.

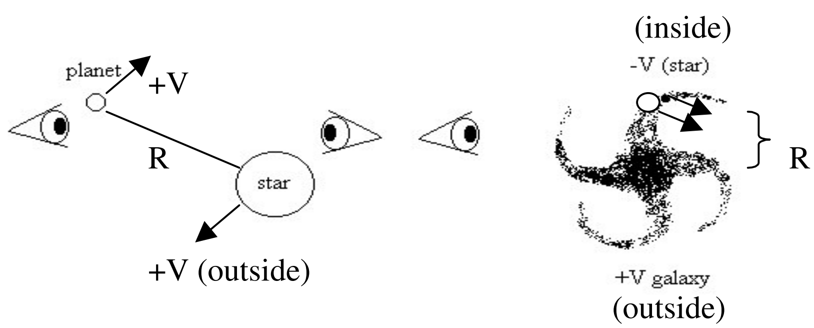


R (kpc)	+Vr (km/s)	-Vv (km/s)
01	049	460.16
02	070	325.38
03	080	265.67
04	090	230
05.4	095	198
06.5	100	180.5
07.5	105	168
08.5	110	157.8
09.7	110	147.75
11	110	138.7
12	110	132.8
13	110	127.6
14	110	122
15	110	118.8
16.2	110	114.3
17.5	110	110

What I call Newton' s Mirror Formula correctly gives the commonly observed rotation curve for galaxies in close agreement with observations. The procedure to flip the Keplerian Decline into its mirror image is simple and straightforward.

Usually we have some data from observations that can be interpreted in terms of radial distances and velocities. So first we plot out the rotation curve from that data and then calculate from the rim inwards to see how well Newton' s Mirror Formula predicts that data. We calculate (Mtot G) by multiplying the rim velocity squared times the rim radius. Then we divide (Mtot G) by each radius value we wish to calculate the velocity for and take the square root of that to get the negative velocity. We plot downwards from the rim velocity as we move in along the radius. Then we adjust the scale according to the cutoff velocity, comparing the curve to the velocity data points gathered from red/blue shift measurements. We map the two rim velocities and the two inner velocities and calibrate the two scales between those two limits.

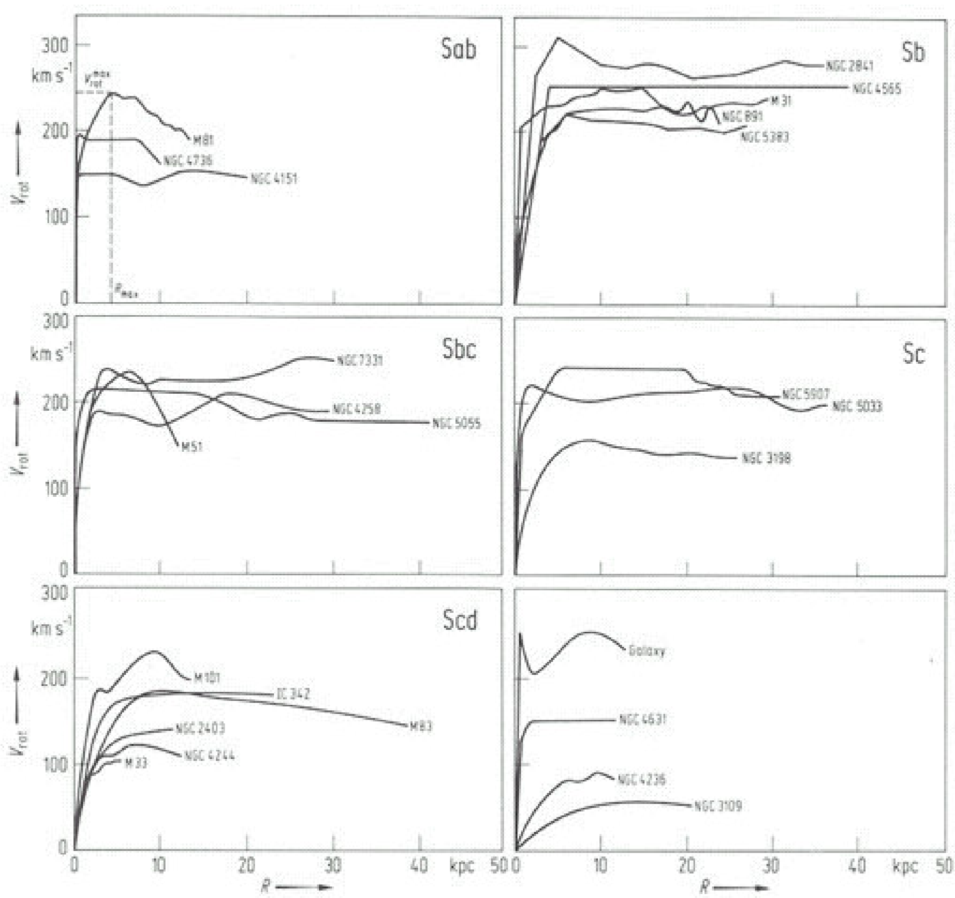
If this simple theoretical framework describes the general rotation curves of spiral galaxies and other large-scale systems, we may be able to settle one of the major headaches in modern cosmology and astrophysics with a generalized Newtonian formula.



Resources

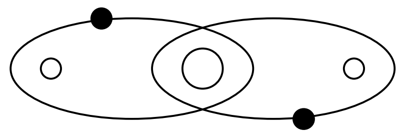
There' s an excellent list of articles by and about Milgrom and his MOND hypothesis accessible on the net at Stacy McGaugh' s "The MOND Pages". I based my sketches of general types of rotation curves on the nice ones done up by Martha Haynes and Stirling Churchman for the Cornell University "Astronomy 201: Our Home in the Universe" website. That site also contains a lot of good photos and data summaries. That also was my source for the UGC 9242 data. The sources for the other examples are listed in the article by each example. This article November 5, 2003, marks the first publication of a theoretical treatment of the MOND hypothesis. My preliminary discussion of MOND without a final theoretical resolution appeared in chapter 15 of **Observer Physics** (Taipei: Delta Point, 2002, 2003). The new edition has been updated to include the latest drafts of these recent rapid research developments. For more insights into gravitational theory, see my monograph, "Gravity and Observer Physics: a New Interpretation." (Taipei: Delta Point, 2003.) The book and monograph are available through the web site: dpedtech.com, or via email: dpedtech@dpedtech.com. To look at lots of rotation curves, see "The data base of spiral galaxies by Courteau" (1996, 1997). This data is available on the Internet as "Rotation Curves and Surface Brightness Profiles of 304 Bright Spirals" in **An Atlas For Structural Studies of Spiral Galaxies**, in the knowledgebase Level 5 section of **NED** (NASA/IPAC Extragalactic Database.)

* Courteau, S. 1996, Ap JS, 103, 363 (photometrics).
* Courteau, S. 1997, A J, 114, 2402 (rotation curves).



25 Rotation Curves Showing Typical Variations in Size, Speed, and Curve Shape

The above sample of rotation curves is based on A. Bosma, Ph.D. Thesis, University of Groningen (1978). It is available in the section on "Rotation, Kinematics, and Dynamics" of "Internal Structure and Dynamics of Galaxies", Basic Data, Level 5 of the **NED** Knowledgebase.



Additional Examples and Methods

Here' s another way to plot a Flipped Newtonian Rotation Curve that may feel more comfortable. Let' s say that the current resolution of your telescope and Doppler equipment is around 1 kpc and 20 km/s. Doing Doppler measurements of such small velocities using hydrogen we must resolve wavelength differences of around .035 nanometer. The margin of error can be quite large, and I would consider 20 km/s is a pretty reasonable margin. Distance measurements are also often being revised. The distance affects the size.

We plot a galactic rotation curve using Newton' s Flipped Formula and our limits of resolution. Let' s say that we look out at NGC 2403 and find that it runs at its asymptote rim velocity at a radius of around 15 kpc. So we set that as our closest instrument reading to "zero" negative velocity -- that is, our error margin of 20 km/s -- translating from our Doppler equipment. This gives us -6000 (kpc) (km/2^2) as our "minimum" negative constant for the rim asymptote. We then use our Flipped Newton Formula to plot off "negative" velocities at various kpc distances along the radius to see our theoretical rotation curve. (Divide by the desired radius and then take the square root.) If our Doppler actually measures the positive asymptote rim velocity at 134 km/s, then our last (innermost) plot will be at [(6000) / (154)^2 = .253 kpc. (-154 - (-154) = 000.) This is the smallest radial distance we can get meaningful data from. Anything from there on in can be going on average anywhere from zero to 20 km/s, but it all gets mushed. That' s our cutoff radius and cutoff velocity. (The negative velocities go relativistic inside that radius.) We call this cutoff (-Vlo) and use that as our asymptote velocity and convert all our negative velocities to positive velocities simply by subtracting the lowest readable negative velocity (-Vlo) calculated at our low limit radial distance (.253 kpc) from each negative velocity (-V). This gives us our theoretical rotation curve for NGC 2403.

R V^2 = (15)(20)(-20) = -6000 (kpc)(km/s)^2.				[-V - (-Vlo)] (km/s)]
R (kpc)	+V (data)	-V	+V (Theoretical Curve Using Newton)	
15	134	20	134	[-20 - (-154) = 134]
14	133	20.7	133.3	[-20.7 - (154) = 133.3]
12	133	22.4	131.6	[and so on]
10	131	24.5	129.5	
08	131	27.4	126.6	

06	130	31.6	122.4
04	124	38.7	115.3
02	095	54.8	099.2
01	077	77.5	076.5
00.253	"000"	154	

I estimated the data from McGaugh's plot in "Testing the Dark Matter Hypothesis.".
The theoretical curve fits the data curve pretty closely, always staying within 10 km/s.

Here is UGC 128. We need to raise our velocity resolution range to around 27 km/s. (For example, see the error margins in McGaugh's plot, also given in "Testing...")

R V^2 = (45) (27)(-27) = -32805 (kpc)(km/s)^2.

R (kpc)	+V (data)	-V	+V (Theoretical Curve Using Newton)	
45	130	27	130	[-27 - (-157) = 130.]
39	129	29	128	
28	128	34.2	122.8	
20	125	40.5	116.5	
15	118	46.8	110.2	
12	107	52.3	104.7	
09.5	090	58.8	098.2	
06	079	73.9	083.1	
04.5	065	85.4	071.6	
03.5	052	96.8	060.2	
02	030	128	029	

I used as a source data by Chris Mihos (see his Applet program on RotCurves. See also the chart in McGaugh and de Blok.) The minimum error range shown on the McGaugh plot for data is at least -27 km/s. Using this margin as our negative asymptote we get a very close fit to the data that stays within 10 km/s throughout the curve.

Here's another example: M33 (NGC 598). I estimated the data from Chris Mihos' site. Setting -V at -25 km/s we get R V^2 = -5250 (kpc)(km/s)^2.

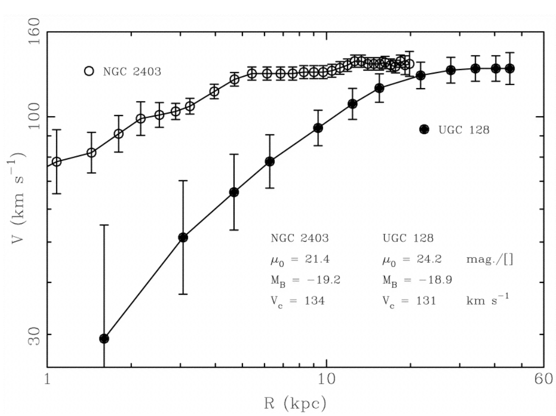
R	-V	+V	+V (data)
8.4	25	108	108
7.2	27	106	106
5.4	31.2	101.8	100
3.6	38.2	094.8	093
2.6	44.9	088.1	085
2	51.2	081.8	078
1.6	57.3	075.7	072
1.2	66.1	066.9	055
1	72.5	060.5	047
.5	102.5	030.5	030

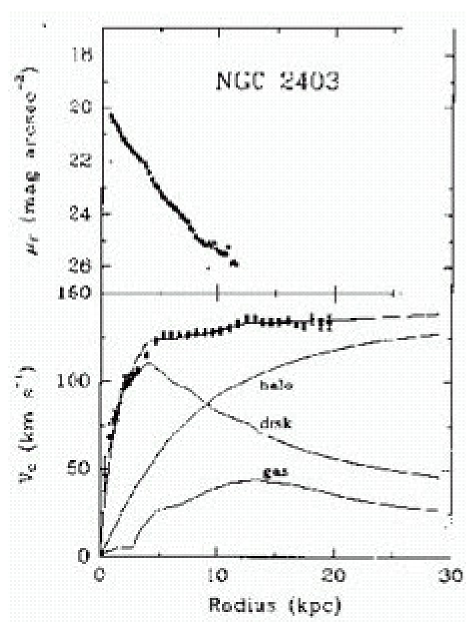
.

When we take a velocity resolution cutoff margin of around -25 km/s, we get a curve that fits the data very closely. Only two points are more than 10 km/s off from my estimations of the Mihos plot. It would help if I had the exact numbers, but these curves are amazingly close considering that the only thing I did was flip Newton over to allow for the observer viewpoint difference and then allow for an instrument resolution cutoff. Please take a good look at this material. All the curves go in this direction. Messing around with huge invisible haloes is just a messy way of fixing things, since we don't see any such substantial haloes. MOND means we have to change Newton's law for some unknown reason. Why not simply take note of the fact that the observer's viewpoint is different when he looks at a galaxy than when he looks at a solar system. Also the instruments have limitations. This is the simple truth. All the curves from galaxies support this simple truth. We do not need to reinvent the universe.

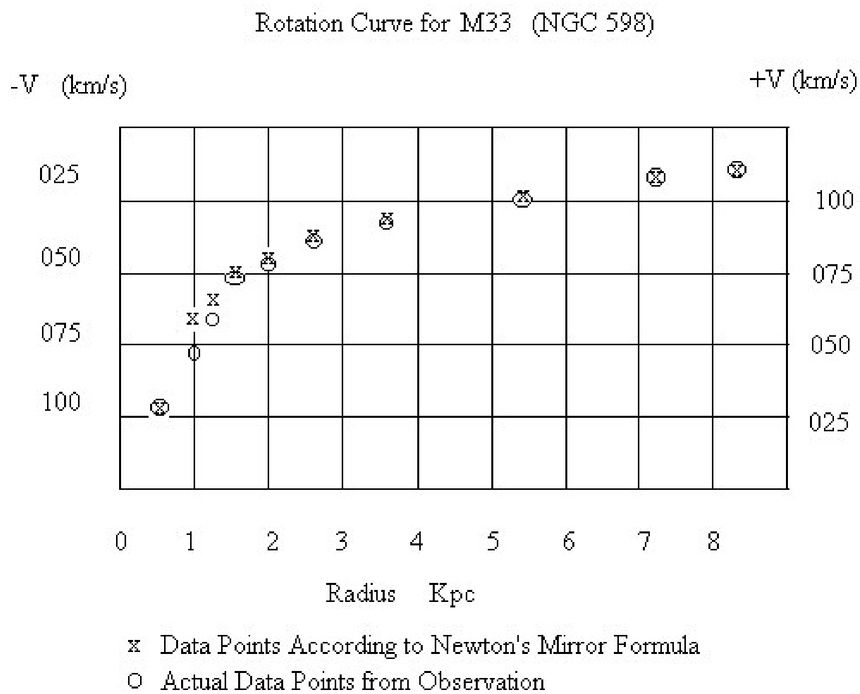
The relativistic argument I gave in the earlier notes still holds, but people may feel more comfortable thinking of "measurement uncertainty" as the key factor in the cutoff, because that is what the "relativistic" onset of "negative velocity" looks like to an observer making the measurements. It's just good old Heisenbergian quantum uncertainty due to the subtlety of the measurements. I see plots of the same galaxy that differ by many kpc's regarding size, simply because it's hard to measure the distance accurately. This also throws the velocities off.

The one thing we all agree on is the general shape of the galactic rotation curve. It is clearly a mirror image of Newton's Keplerian Decline. If the establishment wishes to keep giving galaxies haloes or adding arbitrary factors to Newton's law, I suppose these are imaginative ways of doing astronomy. There are many ways to write equations that "fit" the data. I just think it's nice to know that the physics we already have and the data that we already have are all quite adequate to do the job. Once we agree that everything is generally OK, we can then focus on the details of what happens in specific cases that modify the general pattern.





Above: Plot from McGaugh and de Blok.
Right: Plot from Begeman, 1987.



Based on data plot by Chris Mihos,
shown on his Case Western Reserve University web site.