# Galactic Rotation Curves, Dark Matter and the Evolution of Galaxies

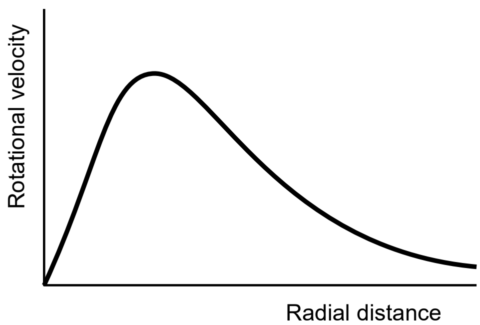

## Abstract

The only evidence for the existence of Dark Matter is to be found in the curious way in which galaxies rotate. All attempts to find Dark Matter here on Earth have failed. An alternative explanation for the anomalous rotation curves of the galaxies is proposed which has the additional benefit of explaining why the early universe contains far more well-formed galaxies than is generally expected.


## Galactic Rotation Curves

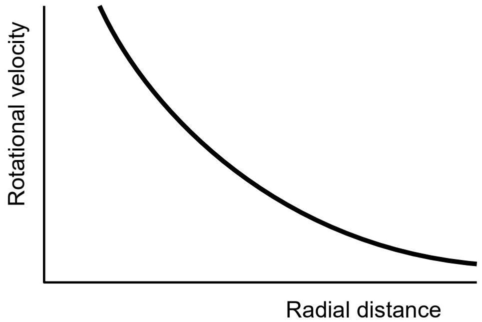
Over half of all the galaxies which we see in the sky are spiral galaxies. Many of them – possibly even the majority – have a supermassive Black Hole at their centre around which a multitude of stars make a stately rotation. Our own Sun is estimated to make a single revolution about the centre of our galaxy in about 250 million years. Since the Sun is about 26,000 light years from the centre this implies that the Sun is moving through space at a speed of around 200 km per hour or 0.065% of the speed of light.

In the 1960's and 70's it became possible to measure the rotation speed of individual stars in nearby galaxies (including our own) using the Doppler effect. When seen edge on, stars on one side of a galaxy will be moving towards us and the light from these stars will be blue-shifted. Stars on the opposite side of the galaxy will emit light which is red-shifted. After suitable corrections are made to account for the tilt of the galaxy, a graph may be plotted of the rotational speed of the stars against their distance from the centre. If we assume that gravity obeys an inverse square law we can make a prediction of the shape of this curve. Close to the galactic centre the rotational velocity of the stars will be very small because there is a relatively small amount of matter 'inside' the stars orbit. As we move away from the centre the rotational speed will rise because more and more matter will lie inside the orbit. At some point, however, the density of stars presumably begins to fall off and in consequence the rotational speed should begin to fall away and stars at a great distance from the galactic centre will, like the outer planets of our own solar system, rotate more and more slowly. The precise shape of the expected curve will depend on the precise way in which the density of the galaxy depends on the radial distance but the general shape will be something like this:




*Galactric rotation curve for a galaxy without a Black Hole*

We now know that many galaxies including our own have a supermassive Black Hole at their centre. For such a galaxy the rotation curve looks a little different. Instead of moving very slowly, the stars close to the Black Hole will have to rotate very rapidly. Burt stars a long way from the centre will not behave any differently from those in a galaxy without a Black Hole. Once the density of stars begins to fall away, the rotational speeds of the stars will fall away too. The galactric rotation curve will look something like this:




*Galactic rotation curve for a galaxy with a Black Hole*

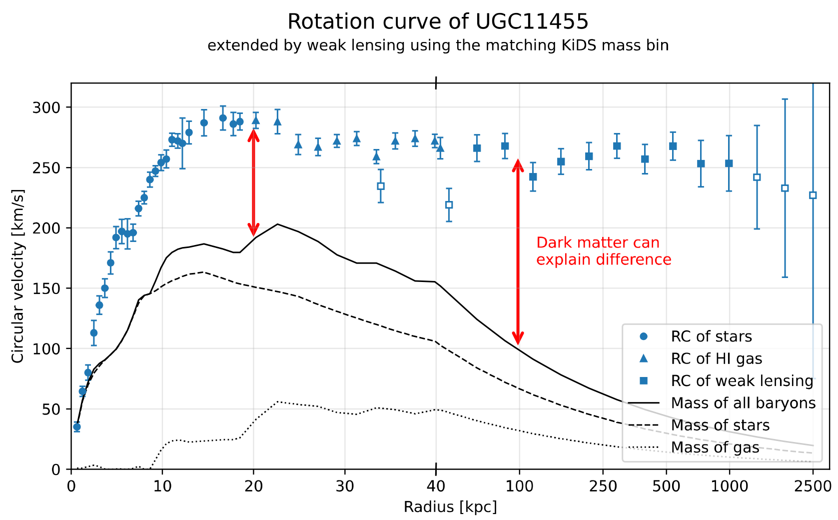
If we make the simplification that most of the mass of the galaxy lies in the central core (whether or not it contains a Black Hole) we can easily predict the shape of this curve. At any radius $r$ the local gravitational field strength must be equal to the centripetal acceleration of the star; hence:

$$\frac{GM}{r^2} = \frac{v^2}{r}$$
$$v = \sqrt{\frac{GM}{r}} \tag{1}$$

In simple terms, a star twice as far from the galactic centre ought to rotate with a speed which is √2 times more slowly.

But in 1975 Vera Rubin, an astronomer at the Carnegie Institution of Washington, made an astonishing announcement. The outer stars of a large number of spiral galaxies all rotate *at the same speed*. Instead of falling off according to an inverse power law, the galactic rotation curves of these galaxies was basically flat.

Here is a modern rotation curve for the galaxy known as UGC11455 using the most up-to-date methods of measurement:




*By ScienceDawns - Own work. Data from.[1][2], CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=180471173*

There is clearly no falling off at all.

The traditional explanation for the discrepancy is that the galaxy must contain large amounts of extra matter which we cannot see – Dark Matter. In fact the amount of Dark Matter required to 'save the appearances' amounts to something like 5 times the amount of visible matter.

The question now arises – what distribution of matter would result in a flat rotation curve?

This is not as easy as it looks to answer because unlike a spherical shell (whose gravitational effect is equivalent to the mass being concentrated at the centre) the gravitational effect of a thin disc or annulus diverges to infinity at the edge. The gravitational effects of a thick disc do not diverge to infinity at the edge but, obviously, the calculations would have to include the thickness of the disc. Notwithstanding these technical difficulties, it is clear that pretty well any rotation curve could be explained by a suitable distribution of Dark Matter either in the disc of the galaxy or in the form of a spherical 'halo' round it.

This, then, is the primary – indeed, the sole evidence – for Dark Matter.

The problem is that, in spite of fifty years of theoretical speculation and experiment in our biggest particle accelerators, absolutely no evidence of the existence of Dark Matter here on Earth has been found. The candidates which have been considered include neutrinos, WIMPs (Weakly Interacting Massive Particles) and MACHOs (Massive Compact Halo Objects) to name but a few but none have been found to fit the bill. This has led a few people to suspect that the search for Dark Matter is futile and that the solution to the problem lies elsewhere.

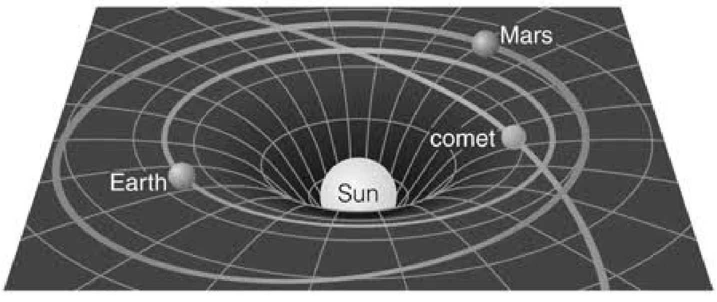
## *Alternative Theories of Gravity*

The basic idea, first proposed by Mordehai Milgrom in 1983, is that the Newtonian law of gravity should be modified when large distances are involved. This idea is called MOND standing for MOdified Newtonian Dynamics. A more modern version of this theory would be to modify Einstein's theory of General Relativity. The problem with this idea, though, is that it is far too specific. If you modify GR in such a way as to explain the rotation curve of UGC11455, what do you do with NGC 1052-DF2 whose rotation curve is perfectly normal? No doubt you could add a few more tweaks to your theory to cope with every eventuality but I am reminded more and more strongly of Ptolemy's attempts to explain the motions of the planets by adding more and more epicycles and inventing more and more exceptions to the basic rule that planets move in perfect circles.

It is obvious to me that astronomers and physicists have been barking up the wrong tree. Let us take it as a fact that a) Dark Matter does not exist and b) Einstein's General Theory of Relativity is correct as it stands. What other possible explanation could there be for the anomalous behaviour of a large number of galaxies?

## *The rubber sheet analogy*

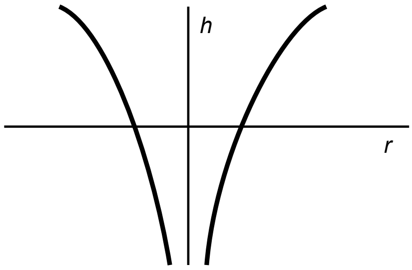
Consider first that popular and useful analogy which is used to 'explain' how curved spacetime can result in what looks like a force of attraction.




*The rubber sheet analogy*

A heavy spherical weight such as a cannon ball is placed in the centre of a circular rubber sheet stretched tight in a circular frame. The weight of the ball distorts the rubber into a funnel shape. A ball bearing thrown into the funnel orbits round the weight in a manner which is highly suggestive of the orbit of a planet round a star. Notwithstanding the many flaws in this analogy, it seems to me to capture the essence of what is going on quite well so I intend to stick with it and see what ideas it can suggest.

We shall start by calculating the shape of the funnel which is needed to model a typical solar system (i.e. a system with a dominant central mass).




*Funnel for a solar system*

Let us suppose that the shape of the funnel (with positive *r*) is defined by a function of *h*. Newton's law of gravitation tells us that the centripetal acceleration is inversely proportional to the square of the orbital radius and we require this to be proportional to the tangent of the slope of the funnel at this radius i.e.

$$\frac{dh}{dr} \propto \frac{GM}{r^2}$$

Integrating this equation gives us:

$$h \propto -\frac{1}{r} \quad \text{(plus a constant)}$$

In other words, the required shape of the funnel is a rectangular hyperbola. If it were not for the effects of friction, such a funnel would enable us to simulate a complete model of the orbits of the planets in our solar system.

The rubber sheet model has been criticised because the funnel shape created by a cannon ball is not a rectangular hyperbola. This criticism is unfair because nobody expects analogies to be accurate models, they are there merely to suggest ideas. We can, however imagine a rubber sheet with non-linear elastic properties (which may even vary from place to place) such that the funnel is the shape of a rotated rectangular hyperbola. Such a sheet would answer our purpose perfectly.

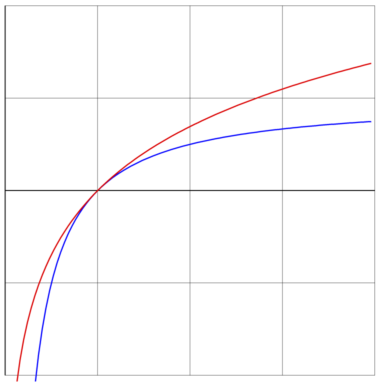
We shall now consider what kind of funnel would model the orbits of the stars in a galaxy whose rotation curve was completely flat. Since all the stars rotate with the same velocity the centripetal acceleration is inversely proportional to the radius i.e.

$$\frac{dh}{dr} \propto \frac{v^2}{r}$$

which gives us

$$h \propto \log(r) \quad \text{(plus a constant)}$$

Now a rectangular hyperbola is not dissimilar from a logarithmic function when *r* is small. Both go to negative infinity at $r = 0$ and both rise monotonically. The only difference is the precise way in which the slope of the funnel changes with height and radius. It is not difficult to imagine a rubber sheet whose elastic properties are such that a weight placed on it would generate a logarithmic rather than a hyperbolic funnel. Such a sheet would provide an excellent model for a galaxy with a flat rotation curve.



*A comparison between a rectangular hyperbola (blue) and a logarithmic curve (red).*

## Anomalous galaxies

Let us leave our rubber sheet for the moment and return to our anomalous galaxies. What exactly can we infer when we see the outer stars rotating more quickly than we expect? Does this *prove* that Dark Matter exists inside the galaxy? No, it does not. All that it shows is that the curvature of spacetime in the vicinity of the star is not what we expect. Einstein's General Theory of Relativity is based on two principles. The first is that the geometry of spacetime is partly determined by the mass/energy which it contains and the second is that freely moving (inertial) objects follow geodesic paths through spacetime. Nobody would dare tamper with the second principle (which largely follows from the definition of an inertial object) but Einstein took 10 years to work out the details of the first principle and there is nothing in the theory that precludes there being causes of spacetime curvature other than the local presence of matter. Indeed, we have recently proved the existence of gravitational waves which are disturbances in the curvature of spacetime which propagate through space at the speed of light without the assistance of any nearby masses.

My proposal is this. In the absence of any nearby masses, *spacetime is not necessarily flat*. It may posses an *intrinsic curvature* which may vary from place to place and which has no external cause.

Imagine a rubber sheet which has been badly manufactured. It is thicker in some places than others and it may also contain 'blisters' where the rubber bubbles up or 'dimples' where it bends down. Toss a ball bearing on this sheet and it will follow a geodesic but its path will be anything but straight. Could it be that the anomalous rotation curves of many galaxies are due to the presence of intrinsic curvature in the vicinity?

## An important objection

Generally speaking, the anomalous rotation speeds are equal and opposite on both sides of the observed galaxy and it is assumed that the supposed distribution of Dark Matter which explains the anomaly is symmetrical about the rotational axis of the galaxy. Likewise, if the anomalous rotation is due to intrinsic curvature then we must suppose that any variations in intrinsic curvature must also be rotationally symmetric. But if galaxies form in random places and if the variations in intrinsic curvature are also randomly distributed, then there is no reason to suppose that there will be any correlation between them. We might imagine that a galaxy formed on the side of a 'dimple' would show a marked difference in velocities of stars on either side of the galaxy[1].

To answer this objection we must look at the way galaxies form in the first place.

1 In fact such differences have actually been detected but the usual practice is produce a single rotation curve by averaging the two figures!

## *The formation of galaxies*

The current theory of galactic formation is that the early universe (say, 100 million years after the Big Bang) consisted of a swirling mass of gas and dust, more or less uniformly distributed throughout space. Due to random fluctuations in density, there were some places where there was a slight accumulation of matter and, due to a positive feedback effect, these regions would attract more and more matter towards them. Owing to the law of conservation of angular momentum, the gas and dust would not simply fall to the centre but would start to rotate around a central core. Meanwhile, within this whirlpool of gas and dust, smaller concentrations of matter would form which would clump together, heat up and become stars.

This scenario is extremely plausible and support for the idea of initial fluctuations in density is found in the measurements of the Cosmic Microwave Background Radiation. But there is one problem. This process is relatively slow, especially in the early stages, and traditional models of galactic formation suggested that it would take 2 or 3 billion years for the first fully formed galaxies to form. Recently, however, deep field images of space taken first by Hubble and now by the James Webb Space Telescope have revealed far more galaxies in the early universe than expected, some little more than 500 million years old. What caused galactic evolution to proceed so rapidly?

Let us stretch (!) our rubber sheet analogy a bit further. Let us liken the early universe to a vast rubber sheet on which are scattered millions of tiny ball bearings in random motion. Each ball bearing makes a tiny dimple on the sheet but as they are initially quite far apart, they do not affect each other very much.

But if there is a slight increase in density of the ball bearings in one region, the cumulative effect of all these little dimples will be a slight lowering of the sheet in this region which will cause all the ball bearings in the region to migrate towards the lowest point. Eventually, so the theory goes, there will be a deep depression in the sheet with ball bearings swirling round it like stars in a galaxy.

My contention is that the early universe already started with slight mounds and depressions which are intrinsic to the fabric of spacetime. Galaxies did not form at random anywhere, they formed where there were already primordial dimples. What is more, these imperfections in spacetime still exist and are the cause of the anomalous rotation curves of many galaxies. This explains why galactic rotation curves are largely symmetrical as galaxies will never form on the side of a dimple. Lastly, since the process is 'seeded' by pre-existing variations in the structure of spacetime, we can expect the process to proceed much more rapidly than the traditional model predicts.

Obviously much work needs to be done to see if this idea is viable mathematically. It also raises the serious question of the origin of these primordial dimples, but it seems obvious to me that, whether or not the idea I have proposed has any mileage in it, the continued search for Dark Matter is futile and new I deas are desperately needed.



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