On the variation of the energy scale 9

Radial Acceleration in Spiral Galaxies

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Fri 7th Oct 2016
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Summary

An empirical relation has been found in spiral galaxies linking the observed radial acceleration to the observed mass distribution. This is surprising as such galaxies are supposed to be dominated by dark matter.

The idea has been put forward that the energy scale varies from region to region and this idea has been used to explain the rotation curves of spiral galaxies without the need to invoke any dark matter. This paper shows that energy scale variations can also explain the observed empirical relation for radial accelerations.

1 Introduction

1.1 A correlation has been found in spiral galaxies between the observed radial acceleration and the observed matter distribution (McGaugh et al, 2016).

1.2 This result is surprising as spiral galaxies are supposed to be dominated by dark matter, which should also dominate the determination of the radial acceleration. Instead it appears that the radial acceleration is related to the observed baryonic matter (stars, gas)

1.3 In Sep 2015 the idea was put forward that the energy scale could vary from location to location (JoKe1, 2015). This idea enabled the rotation curves of spiral galaxies to be explained without the need for any dark matter.

1.4 Other papers have shown that energy scale variations can also help explain: the primordial density perturbations and the fluctuations in the cosmic microwave background (JoKe8, 2016); the large velocities of galaxies in clusters (JoKe4, 2015); collisions between galaxy clusters (JoKe5, 2015); gravitational lensing (JoKe7, 2016).

1.5 This paper goes back to spiral galaxies and examines whether or not energy scale variations can explain the radial acceleration relationship of McGaugh et al (2016).

2 Radial acceleration in spiral galaxies

2.1 We model a spiral galaxy as a rotating disk having a density distribution that varies with distance from the centre and a rotational speed that also varies with distance.

2.2 Newtonian dynamics and Newtonian gravity show that the radial acceleration, $A(r)$, at a point in the rotating disk is given by:

$$A(r) = \frac{v^2}{r} = \frac{G\,M(r)}{r^2} \tag{1}$$

where v is the rotational speed; r is the radial distance; $M(r)$ is the mass interior to r.

2.3 In JoKe3 (JoKe3, 2015) the galaxy lies embedded in an energy scale variation with a Gaussian distribution. The radial acceleration, $A_J(r)$, is given by:

$$A_J(r) = \frac{v^2}{r} = \frac{G\,M(r)}{r^2}\,\frac{1}{Q(r)}\int_0^r Q(x)\;P(x)\,dx \tag{2}$$

2.4 The energy scale variation term, $Q(x)$, is given by

$$Q(x) = 1 + \gamma\,exp(-r^2/\alpha^2) \tag{3}$$

where γ is a pure number; α is the 1/e-width of the Gaussian energy scale variation.

2.5 In JoKe3 a Gaussian density distribution is assumed in which case the density distribution term, $P(x)$, is given by

$$P(x) = \frac{2x}{\beta^2}\,exp(-x^2/\beta^2\,) \tag{4}$$

where β is the 1/e-width of the Gaussian density distribution.

2.6 For a point mass, M, equation (2) reduces to:

$$A_J(r) = \frac{v^2}{r} = \frac{G\,M(r)}{r^2}\left\{\frac{1+\gamma}{1+\gamma\,exp(-r^2/\alpha^2)}\right\} \tag{5}$$

2.7 For small r, the bracketed term in equation (5) has the value 1. So near the centre of the galaxy we expect normal Newtonian gravity to apply as given by equation (1).

For large $\boldsymbol{r}$, the bracketed term tends to the constant value $\{\mathbf{1} + \boldsymbol{\gamma}\}$. So at large distances from the galaxy centre, Newtonian gravity also applies, but with a larger effective mass.

2.8 For the idea of energy scale variations we are now in a position to compare the observed radial acceleration with the expected radial acceleration.

$\boldsymbol{A(r)}$, as given by equation (1), is the expected radial acceleration.

$\boldsymbol{A_J(r)}$, as given by equation (2) or (5), is the observed radial acceleration.

2.9 In the limiting case of a point mass galaxy we have from equations (1) and (5):

$$\frac{\boldsymbol{acc}(\boldsymbol{observed})}{\boldsymbol{acc}(\boldsymbol{expected})} = \frac{\boldsymbol{A_J}(\boldsymbol{r})}{\boldsymbol{A}(\boldsymbol{r})} = \left\{\frac{\mathbf{1} + \boldsymbol{\gamma}}{\mathbf{1} + \boldsymbol{\gamma}\, \boldsymbol{exp}(-\boldsymbol{r}^{\mathbf{2}}/\boldsymbol{\alpha}^{\mathbf{2}})}\right\} \qquad (6)$$

This has the value of 1 near the galaxy centre and the asymptotic value $\{\mathbf{1} + \boldsymbol{\gamma}\}$ at large distances.

3 Example: galaxy NGC 5055

3.1 We illustrate the workings of section 2 (above) by looking at galaxy NGC 5055.

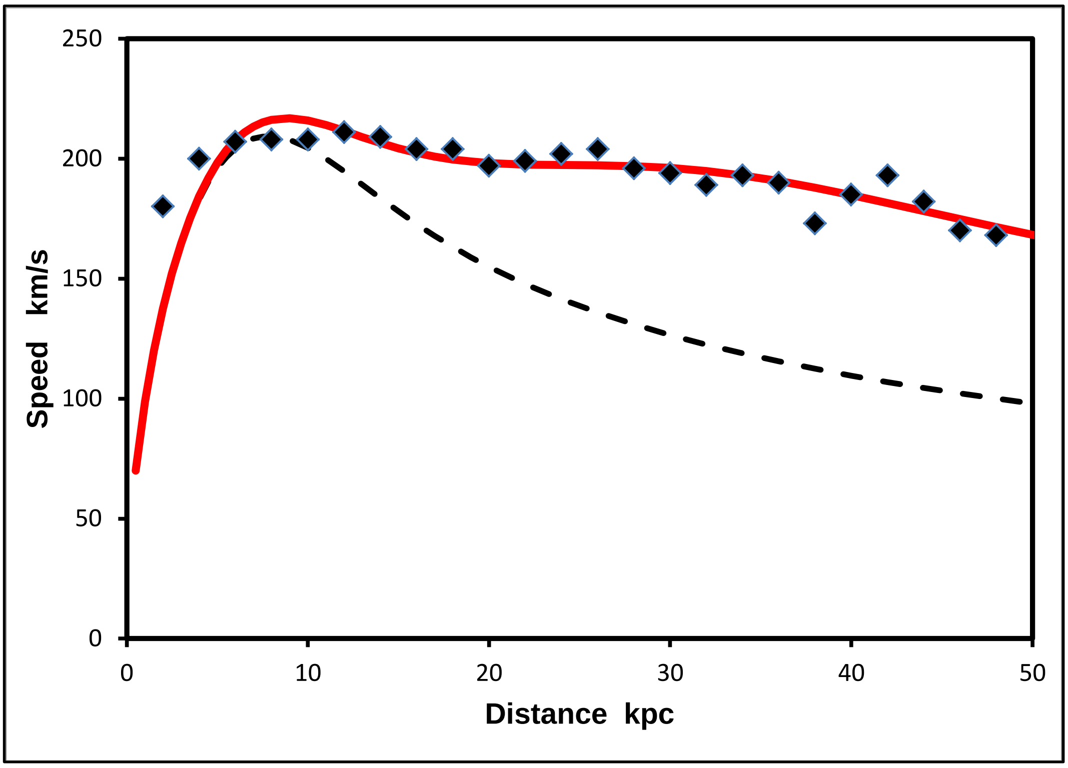

Figure 1. The rotation curve for galaxy NGC 5055. The black diamonds are the observed values. The solid red line is the rotation curve, as given by equation (2). The dashed black line is the expected curve for Newtonian gravitation, equation (1), for the same mass distribution as used in (2).

3.2 Figure 1 is taken from JoKe2 (JoKe2, 2015). Considering the scatter in the observations the fit (solid red line) is pretty good for most of the curve. And It begins to show the expected 1/r fall off at large distances. The fit is poor for the galaxy centre where the assumed Gaussian density distribution is clearly wrong.

3.3 Figure 2 shows the ratio of acceleration(observed) to acceleration(expected) for NGC 5055 based on equation (1) and (2). The ratio is close to 1 near the galaxy centre showing that the acceleration is given by Newtonian gravitation arising from the matter present. The figure also shows the curve tending towards an asymptotic value at large distances from the galaxy centre.

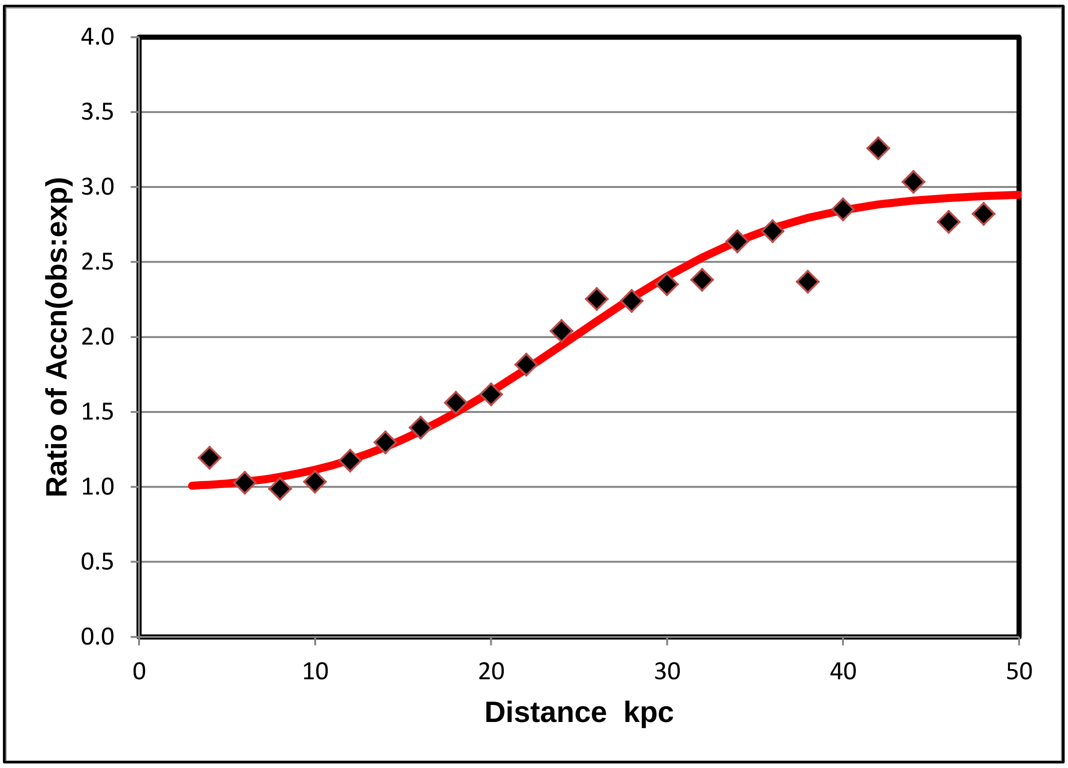

Figure 2. The ratio of acceleration(observed) to acceleration(expected) for NGC 5055.

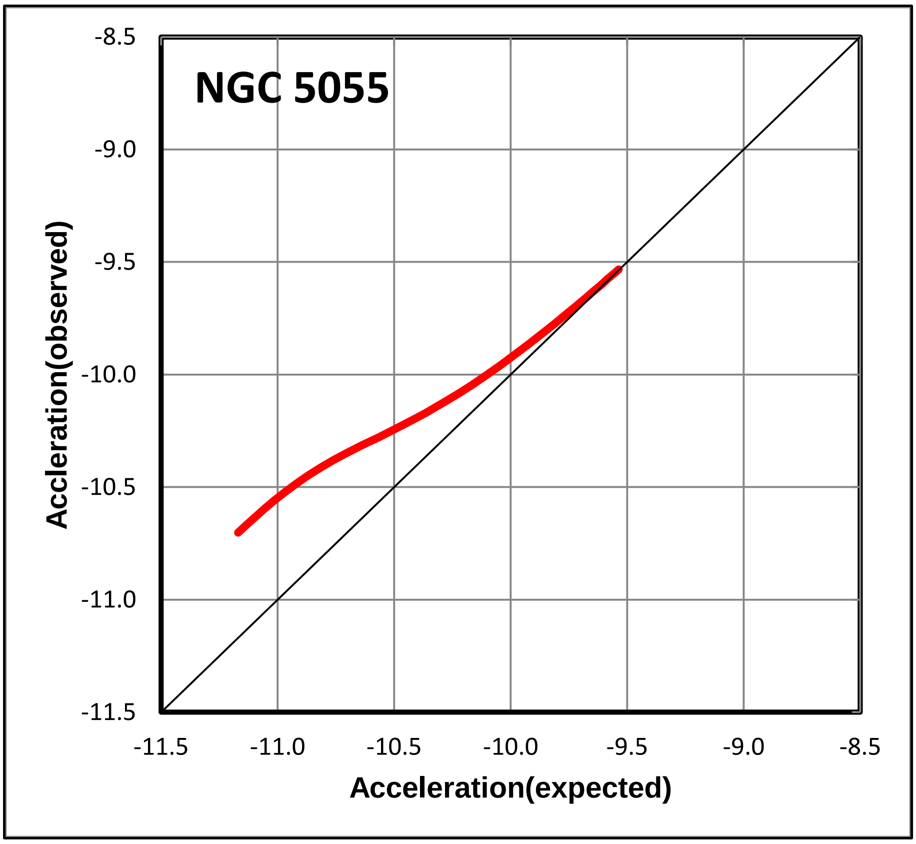

Figure 3. Acceleration(observed) against acceleration(expected) for NGC 5055.

3.4 Figure 3 shows the same curve as in Figure 2, but displayed on the diagram used by McGaugh et at (2016). The galaxy centre, with high values of acceleration, is towards the top and lies on the line y=x. The outer regions of the galaxy, with lower accelerations, are towards the bottom and lie away from the line y=x.

4 Radial accelerations for several galaxies.

4.1 We can now construct the acceleration diagram for a number of galaxies to see if we can reproduce the result of McGaugh et al (2016). We choose the six galaxies from JoKe2 (JoKe 2, 2015).

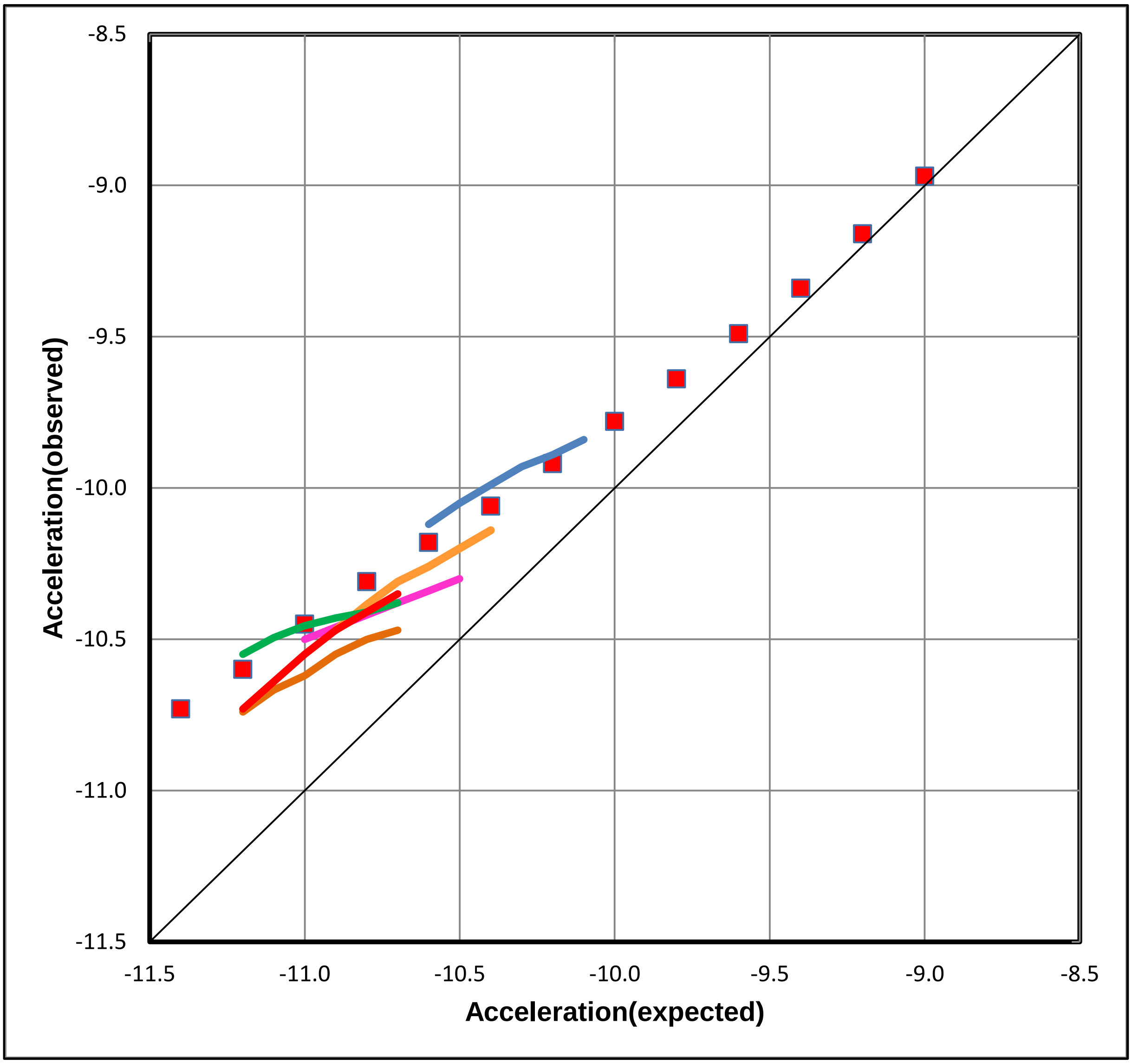

Figure 4. The radial accelerations (observed vs expected) for six galaxies: Only the data for the outer regions of the galaxies are plotted. The red squares are from McGaugh et al (2016) and show the single curve found to be followed by most galaxies.

4.2 Figure 4 shows the data for galaxies: NGC 2403; NGC 2841; NGC 2903; NGC 3198; NGC 3621; NGC 5055. These are the galaxies used in JoKe2 (JoKe2, 2015).

4.3 Only the data for the outer regions of each galaxy is plotted. This is deliberate because the inner regions are not well determined.

4.4 Figure 4 does not show a single curve that is the same for all galaxies. However, if we combined all the curves then we would end up with a reasonably narrow band within which most galaxies would lie.

4.5 Figure 4 does not plot observed data values. The values of 'observed acceleration' are those for the model fit using equation (2). This model fit also determines the mass distribution. So the values of 'expected acceleration' are those expected for the mass given by the model.

4.6 If galaxies are smooth disks with Gaussian density profiles and if they are embedded in energy scale variations with a Gaussian profile then we expect their accelerations to look like those in Figure 4.

4.7 It is clear from Figure 4 that energy scale variations have the potential to explain the radial acceleration relation found by McGaugh et al (2016).

4.8 On the positive side the accelerations illustrated in Figure 4 are determined by the actual mass and not by a separate (uncorrelated) distribution of dark matter.

5 Conclusion

5.1 We apply the hypothesis of variations in the energy scale to the radial acceleration relation for spiral galaxies found by McGaugh et al (2016).

5.2 The acceleration data for six galaxies does not reproduce the single curve identified by McGaugh et al (2016). However, the data go some way to reproducing the curve and if combined would give rise to a narrow band, similar to McGaugh et al, within which most galaxies would lie.

5.3 None of the data used are real observed values: all are derived from the simple galaxy model of a Gaussian density distribution embedded in a Gaussian energy scale variation.

5.4 It would be a useful exercise to extend this work to cover the 153 galaxies used by McGaugh et al (2016) in their paper.

6 References

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