On the variation of the energy scale 14

Structure Formation

by

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Summary

The fluctuations in the cosmic microwave background (CMB) are at the level of a few parts per hundred thousand. This is too low for structures, such as galaxy clusters and galaxies, to form fast enough under gravity using just the observed baryonic matter. The current solution to this problem is to invoke the existence of large amounts of dark matter that provide the required gravitational wells.

It has been proposed that the energy scale can vary from location to location. Simple numerical calculations show that energy scale variations provide gravitational wells and enable structures to form rapidly in the early Universe without the need for any dark matter.

1 Introduction

1.1 The leading model for explaining the history of the Universe is the ΛCDM model (Λ=cosmological constant, Cold Dark Matter). The early history can be summarised as follows (Ryden 2017; Weinberg 2008):

a) creation followed by a period of rapid expansion (inflation)
b) a period (~50,000 years) of radiation dominating matter. Normal baryonic matter is fully ionised and gravitational accretion does not occur. Gravitation accretion does occur for non-baryonic dark matter.
c) after ~50,000 years baryonic matter, which is still ionised, begins to become dominant and some gravitational accretion can start. Dark matter continues to accrete.
d) 380,000 years baryonic matter becomes neutral and the Universe becomes transparent to radiation. This stage is observed as the cosmic microwave background (CMB). Fluctuations in the CMB (and hence in the baryonic matter) are of the order of 1 part in 100,000. Dark matter has continued to accrete and substantial gravitational wells exist.
e) next few hundred million years. Baryonic matter falls into the dark matter gravitational wells and structures appear that eventually form voids, galaxy clusters, and galaxies.

Dark matter is crucial for this history of the early Universe; without it the structures that are observed to exist by 1.5 billion years could not have formed.

1.2 The idea has been put forward that the energy scale can vary from location to location (JoKe1, 2015). This idea enables the rotation curves of spiral galaxies to be explained without the need for any dark matter. JoKe2 (2015) improved the model of JoKe1 to include a Gaussian density distribution for the galaxy and a Gaussian distribution for the energy scale variation. JoKe3 (2015) applied the model of JoKe2 to a set of 74 spiral galaxies. Parameters were obtained that defined the energy scale variations, as well as values for the galaxy mass and rotational velocity.

1.3 Other papers in the series deal with: clusters of galaxies; collisions between clusters of galaxies; galaxy interactions; gravitational lensing; primordial density perturbations; cosmology.

1.4 This paper looks into applying energy scale variations to the problem of structure formation in the early Universe.

2 Variations of the Energy Scale

2.1 As first put forward in JoKe1 (2015) we assume that the energy scale can vary from location to location.

2.2 By this we mean the energy, E, of an object at location X as measured by an observer at location A is given by

$$\xi_A \, E_{AX} \;=\; \xi_X \, E_{XX} \tag{1}$$

where ξ is a dimensionless function, a pure number.

2.3 E_{AX} is "the value of the energy at X as measured by an observer at A". Similarly E_{XX} is the 'intrinsic' value of the energy at X as measured by an observer also at X.

2.4 The function ξ is a scalar function of position (and time)

$$\xi \;\equiv\; \xi(x, y, z, t) \;>\; 0 \tag{2}$$

ξ is dimensionless, i.e. it has no units, and must be a pure number greater than zero. ξ can never be zero.
A two-dimensional representation of equation (1) is shown in Fig 1.

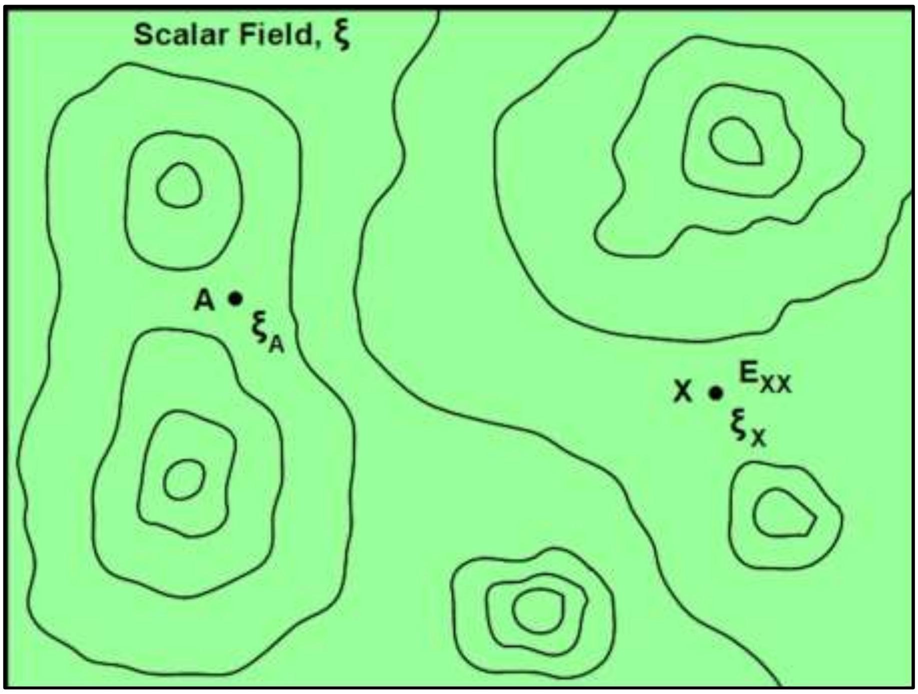

Fig 1. Illustration of the scalar field, ξ, which characterises the variation of the energy scale. An observer at A measures the energy, E, of an object at X as given by equation (1).

2.6 Another way of phrasing equation (1) is:
For an observer at A, an object at X behaves as if its energy is (ξ_X/ξ_A) its intrinsic value.

2.7 Equation (1) does not simply apply to energy, but to all quantities that have energy as part of their units. If we move away from the usual units of mass, length & time to units of length, speed & energy then other quantities that are also affected include: momentum; force; energy density; pressure.

2.8 In most situations a variation of the energy scale has no impact. This is because in any physical equation the units on both sides balance and the ξ factors cancel out. This is obviously true for situations where everything (observer, object) happens at the same location. This clearly applies to experiments using particle accelerators.

2.9 However, for gravitational interactions the masses are invariably at different locations.

2.10 We assume that variations only occur to the energy scale and not to the length or speed scales.

3 Gravitational Acceleration

3.1 We consider the two-dimensional case of two masses $\boldsymbol{m_A}, \boldsymbol{m_B}$ at locations $\boldsymbol{A}(\boldsymbol{x_A}, \boldsymbol{y_A}), \boldsymbol{B}(\boldsymbol{x_B}, \boldsymbol{y_B})$ separated by a distance $\boldsymbol{r}$. Newtonian gravity gives the acceleration as

$$\ddot{\boldsymbol{x}}_{\boldsymbol{B}} = -\frac{\boldsymbol{G}\,\boldsymbol{m_A}}{\boldsymbol{r}^3}(\boldsymbol{x_B} - \boldsymbol{x_A}) \tag{3}$$

(similarly for $\ddot{\boldsymbol{y}}_{\boldsymbol{B}}, \ddot{\boldsymbol{x}}_{\boldsymbol{A}}, \ddot{\boldsymbol{y}}_{\boldsymbol{A}}$)

3.2 Introducing the double suffix notation of equation (1) this becomes

$$\ddot{\boldsymbol{x}}_{\boldsymbol{BB}} = -\frac{\boldsymbol{G}\,\boldsymbol{m_{BA}}}{\boldsymbol{r}^3}(\boldsymbol{x_B} - \boldsymbol{x_A}) \tag{4}$$

This involves the remote value, $\boldsymbol{m_{BA}}$, i.e. the value of the mass at A as measured by an object (observer) at B. We need to replace this with the intrinsic value, $\boldsymbol{m_{AA}}$.

3.3 Equation (1) for mass, $\boldsymbol{m_A}$, is (ignoring possible variations in the scales for length and speed):

$$\boldsymbol{\xi_B}\,\boldsymbol{m_{BA}} = \boldsymbol{\xi_A}\,\boldsymbol{m_{AA}} \tag{5}$$

3.4 Applying (5) to (4) gives

$$\ddot{\boldsymbol{x}}_{\boldsymbol{BB}} = -\frac{\boldsymbol{G}\,\boldsymbol{m_{AA}}}{\boldsymbol{r}^3}(\boldsymbol{x_B} - \boldsymbol{x_A})\left\{\frac{\boldsymbol{\xi_A}}{\boldsymbol{\xi_B}}\right\} \tag{6}$$

3.5 Equation (6) means that, depending on the function $\boldsymbol{\xi}$, the acceleration can be greater than or less than that expected for normal Newtonian gravity. It is this hypothesis that is used in JoKe1 to explain the flat rotation curves of spiral galaxies.

4 Gaussian Variation

4.1 As in previous papers we adopt a Gaussian profile for the variation of the energy scale. This is illustrated in Fig 2.

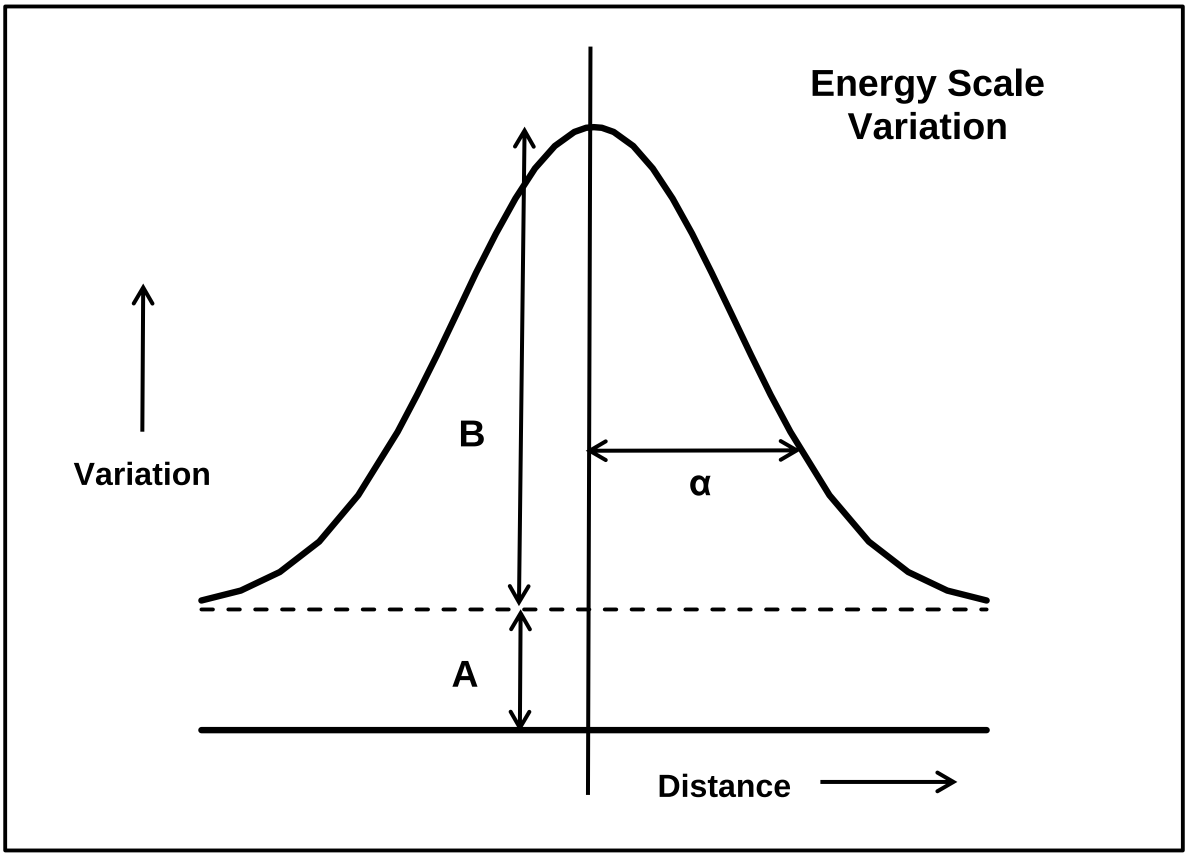

Fig 2. Gaussian energy scale variation. **B** the height; α the 1/e-width; **A** is the base value.

4.2 The equation for the variation of the energy scale, $\boldsymbol{\xi}$, is

$$\boldsymbol{\xi} = \mathbf{1} + \boldsymbol{\beta}\, \boldsymbol{exp}(-\boldsymbol{r}^{\mathbf{2}}/\boldsymbol{\alpha}^{\mathbf{2}}) \tag{7}$$

where

$$\boldsymbol{\beta} = \boldsymbol{B}/\boldsymbol{A} \tag{8}$$

$\boldsymbol{\beta}$ is a pure number, representing the height of the variation, and is constant for a given variation of the energy scale; $\boldsymbol{\alpha}$ is the 1/e-width, a distance, and is constant for the same variation of the energy scale.

5 Numerical Simulations

5.1 We carry out some simple numerical simulations of the effects of an energy scale variation on the evolution of a group on masses restricted to just two dimensions.

5.2 250 points of equal mass (1 unit) are randomly placed within a two-dimensional square. Every mass is given a velocity selected randomly from a fixed range. (The masses do not have a Maxwellian or Gaussian distribution of velocities.)

5.3 The masses can attract one another. A small collision radius is imposed. If two masses approach closer than the collision radius then the pair merge into a single mass. The mass is the sum of the masses; the momentum is the sum of the momenta. So mass and momentum are both conserved.

5.4 There is a central mass of 10 units. This is rigidly fixed to the centre of the square. It can grow in mass by gravitational attraction. The central mass uses the same collision radius as the other masses. The central mass is immovable and simply ignores the momentum of the masses it swallows.

5.5 The simulation is run twice. First with just Newtonian gravitation where the acceleration of a given mass is given by equation (4) summed across the other masses. Second with Newtonian gravitation and a variation of the energy scale. Here the acceleration is given by equation (6).

5.6 The variation of the energy scale is centred on the central mass. The variation is given by equation (7) with the height β=20 and 1/e-width, α, set to 10% the distance from centre to edge.

5.7 The following pages show the results of 4 runs of the simulation. For each run the masses have a different set of random positions and a different set of random velocities. The simulation is run for 300 time steps. The figures show the initial position and time steps 50, 100, 300. The right-hand figures (green) are for Newtonian gravity. The left-hand figures (purple) are for Newtonian gravity and an energy scale variation.

5.8 The computer program for the numerical simulations is written in Python and run on an IBM PC running Windows 10.

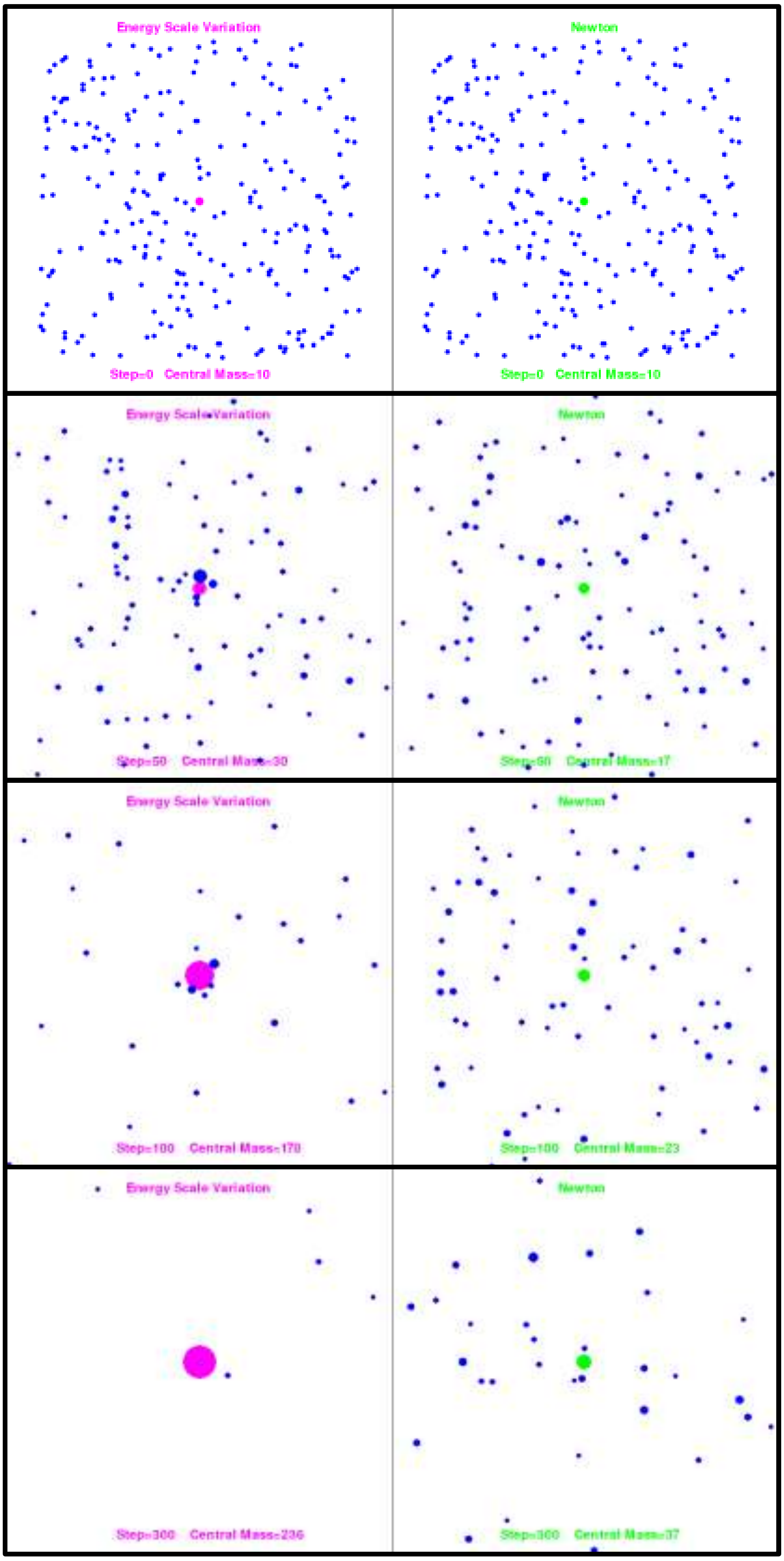

Fig 3. Run 1. Evolution of 250 randomly placed masses with random speeds. Right side is simple Newtonian gravity; left side includes an energy scale variation.

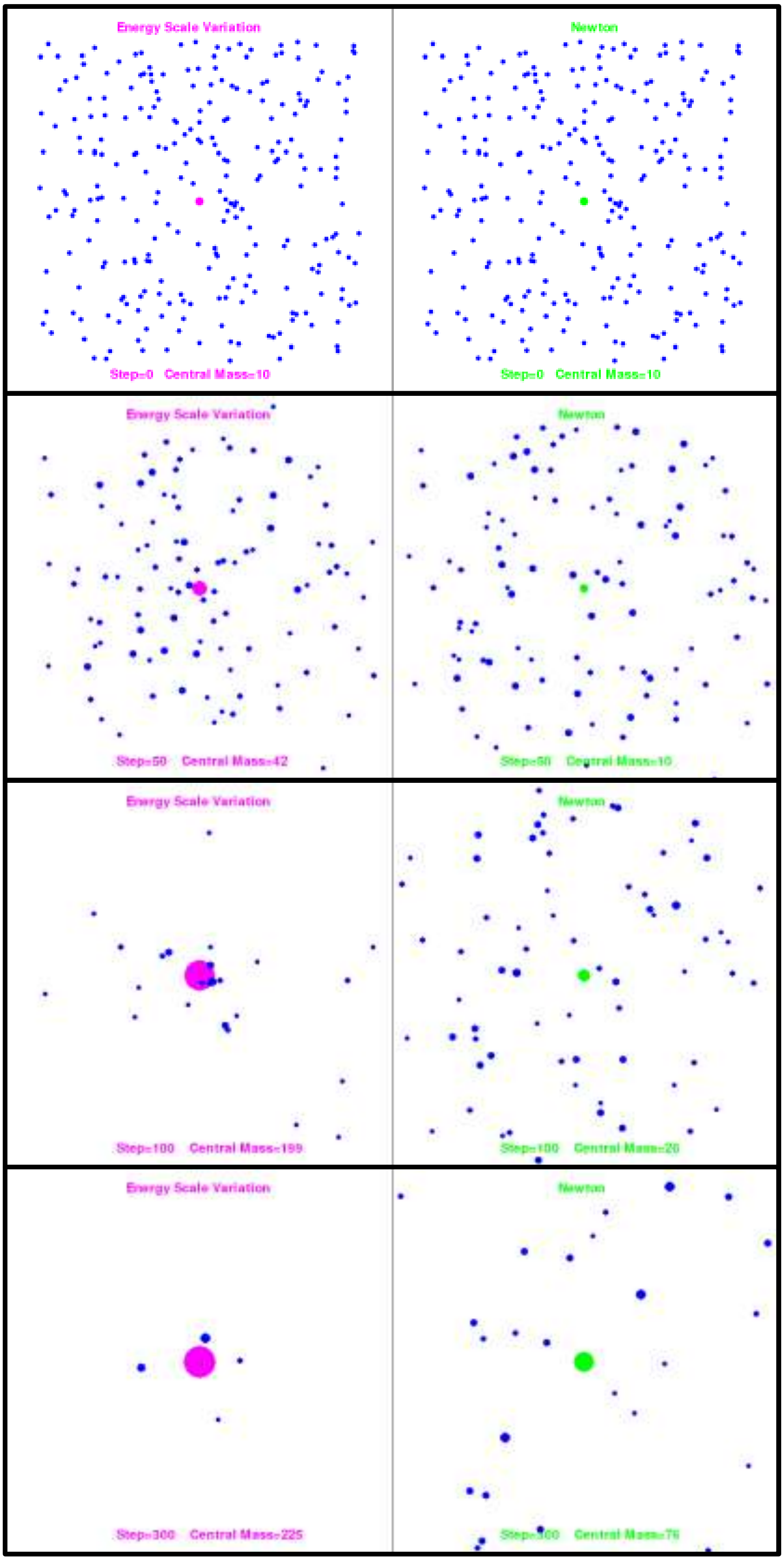

Fig 4. Run 2. Evolution of 250 randomly placed masses with random speeds. Right side is simple Newtonian gravity; left side includes an energy scale variation.

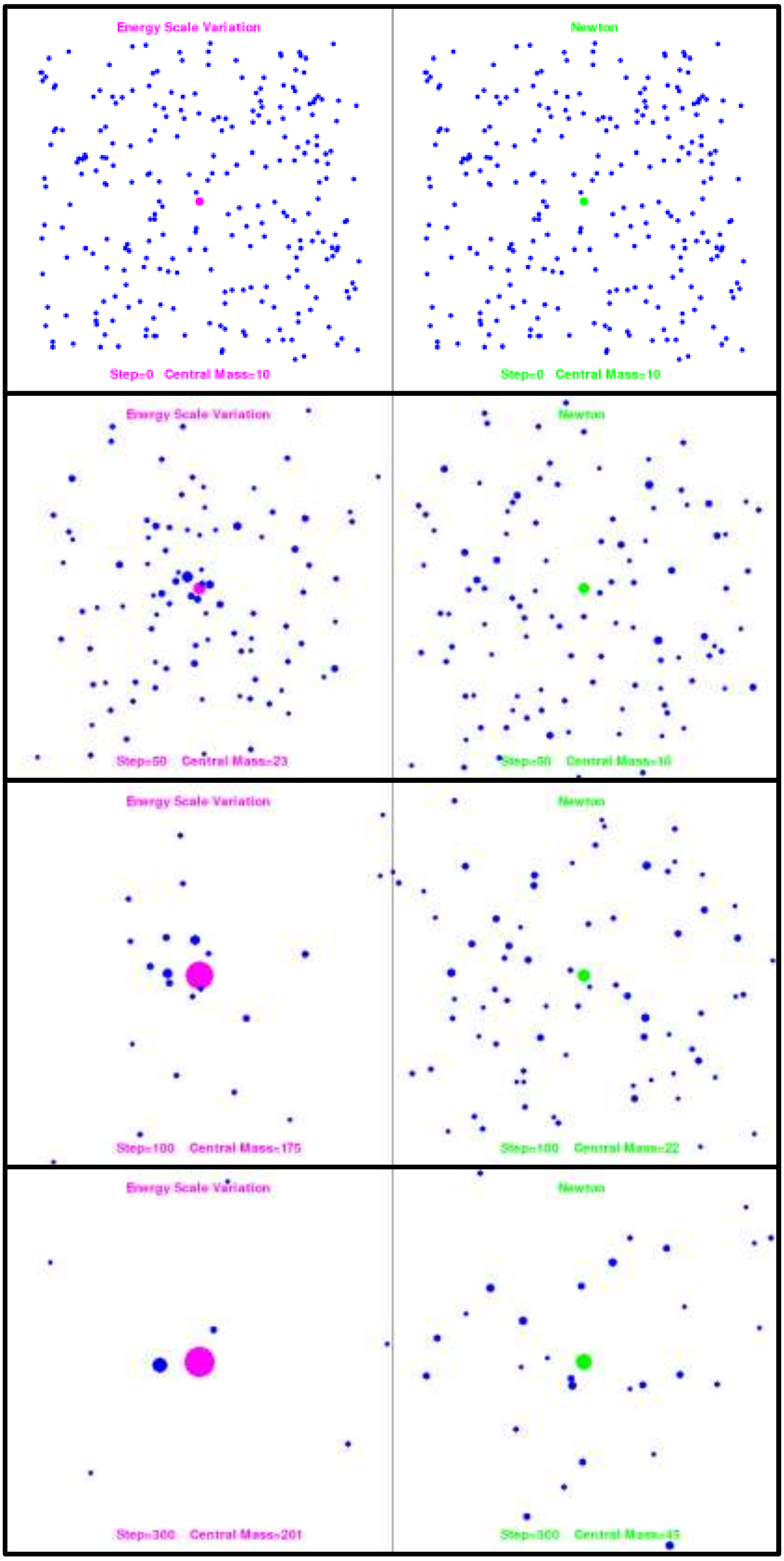

Fig 5. Run 3. Evolution of 250 randomly placed masses with random speeds. Right side is simple Newtonian gravity; left side includes an energy scale variation.

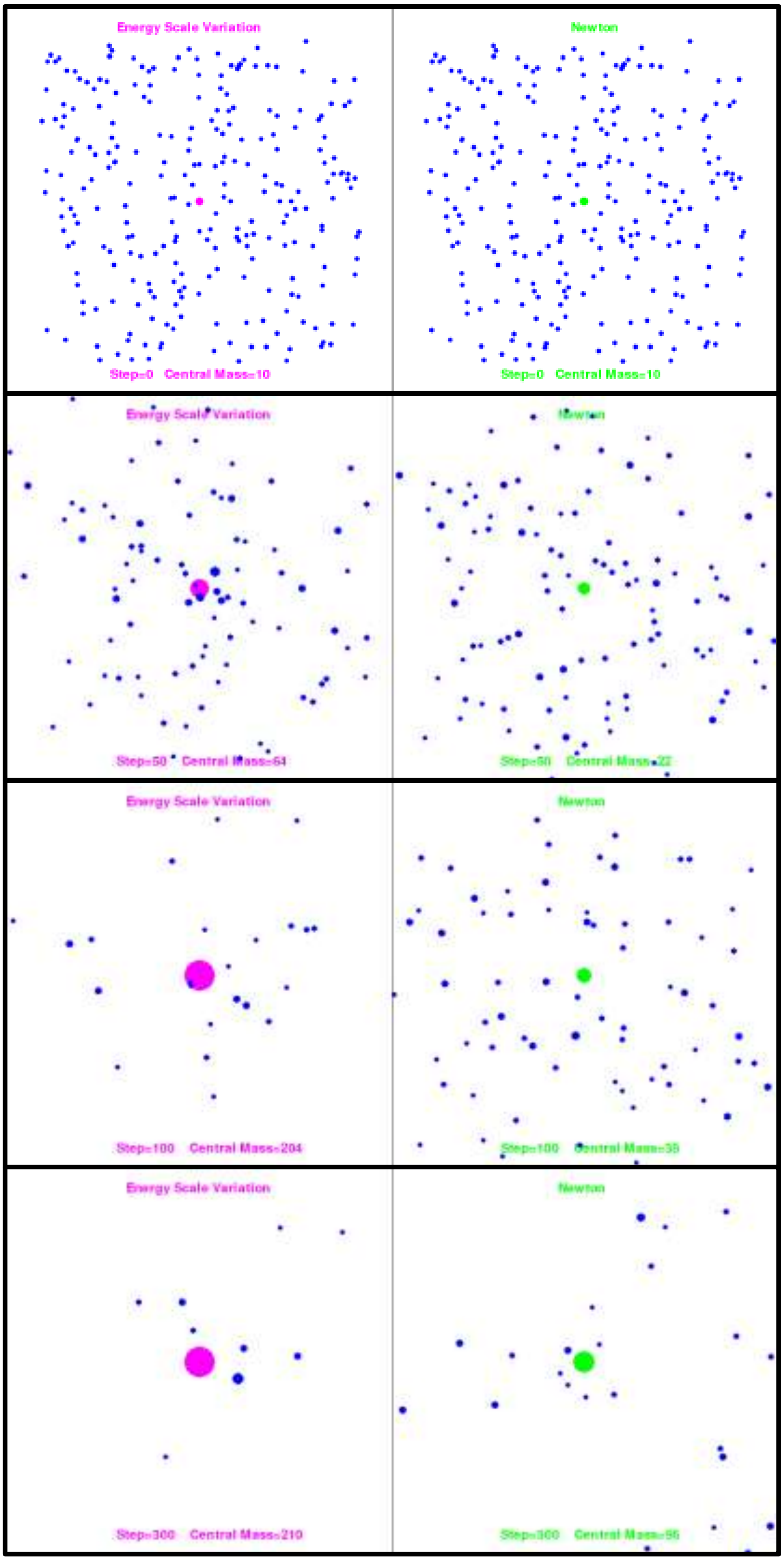

Fig 6. Run 4. Evolution of 250 randomly placed masses with random speeds. Right side is simple Newtonian gravity; left side includes an energy scale variation.

6 Discussion

6.1 The starting point for the simulations is a two-dimensional plane with 250 unit masses scattered randomly over a square region. Additionally there is a single central mass of 10 units. So the simulation is two-dimensional and not three-dimensional as in real space.

6.2 Dividing the square region into a 5x5 grid, each square contains 10 unit masses on average with a mass of 20 in the central square. This roughly corresponds to a uniform density plane with a central enhancement of a factor of two. This is somewhat different from the 1 part in 100,000 of the CMB.

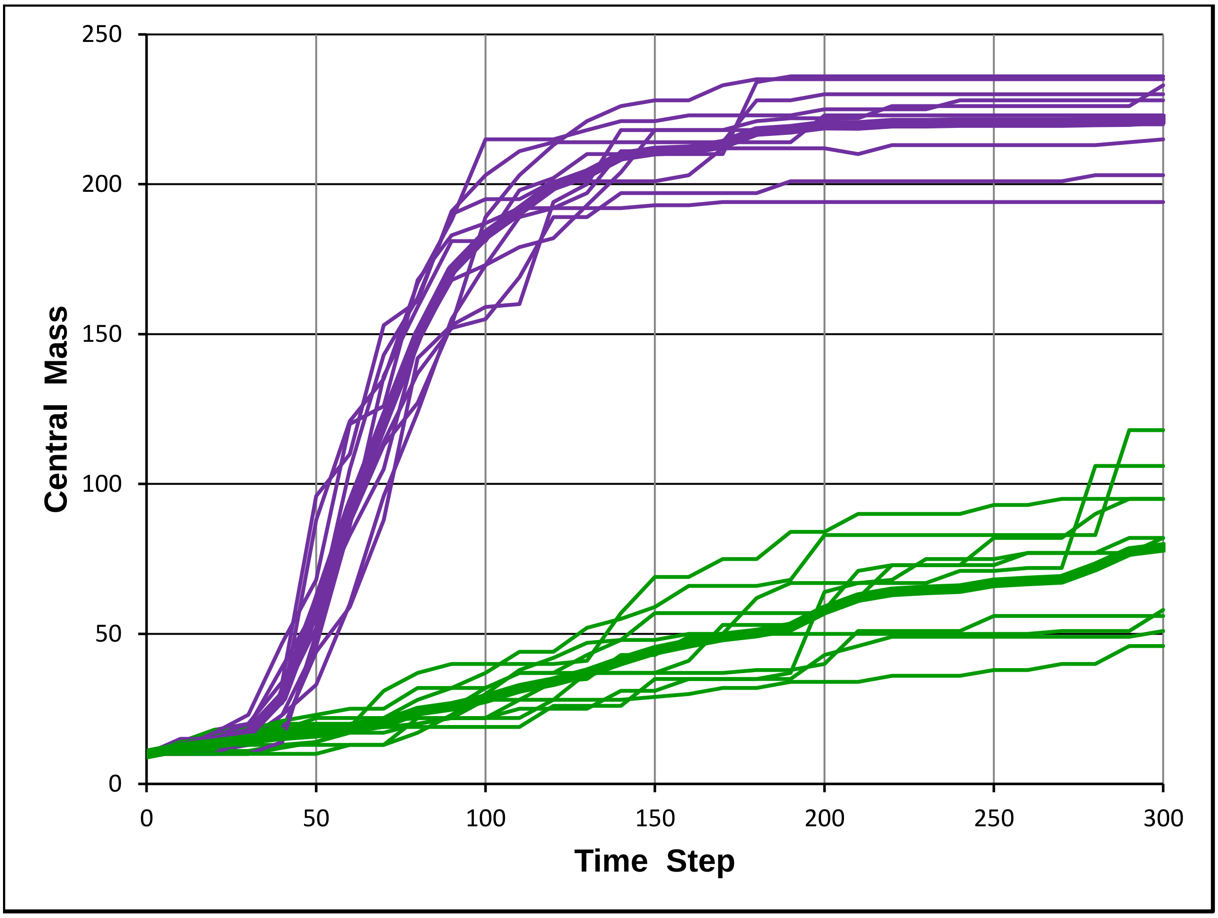

Fig 7. Growth of the central mass for 10 runs of the numerical simulation. The green lines are for Newtonian gravitational; the purple lines are for Newtonian gravity plus an energy scale variation. The thick lines are the averages of the runs.

6.3 Figs 3 to 6 show snapshots for 4 simulations at 4 different time steps (0, 50, 100, 300). It is clear that the addition of the energy scale variation makes a substantial difference to the behaviour, with the central mass growing much faster than for Newtonian gravity alone.

6.4 The simulations show that some masses have sufficiently large velocities to either escape completely or never get swallowed by the central mass. This accounts for around 20% of the masses.

6.5 The simulations also show that masses can coalesce away from the centre. This means the overall spread of matter becomes lumpier as time goes on.

6.6 Fig 7 shows the growth of the central mass for 10 simulations. The thick lines show the average growth. It is again clear that an energy scale variation means the central mass growths at a very fast rate, around 5 times faster than for Newtonian gravity on its own.

6.7 The energy scale variation chosen for the simulations was to some extent arbitrary. If it had been weaker then growth would have been slower. If it had been stronger then growth would have been faster.

6.8 The main point of the simulations is that they demonstrate that structure formation in the Universe between the time of the Cosmic Microwave Background (~400,000 years) and 1.5 billion years (galaxy clusters, galaxies, voids) can happen without the existence of any dark matter.

7 References

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