On the variation of the energy scale 13

Inflation

by

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Summary

The idea has been put forward that the energy scale can vary from location to location. This idea has been used to explain the rotation curves of spiral galaxies and other observations without the need for any dark matter. Energy scale variations can also explain the accelerated expansion of the Universe without the need for any dark matter, dark energy, or a cosmological constant. This paper looks at whether energy scale variations can say anything about inflation.

It turns out that variations in the energy scale naturally give rise to a period of power law inflation (rather than exponential inflation) during the radiation-dominated early Universe.

1 Introduction

1.1 In Sep 2015 the idea was put forward that the energy scale might 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. 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.

1.2 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 this series have dealt with: clusters of galaxies; collisions between clusters of galaxies; galaxy interactions; gravitational lensing; primordial density perturbations.

1.4 Joke12 (2017) applied energy scale variations to the equations of cosmology and showed that they could explain the apparent accelerated expansion of the Universe without any dark matter or dark energy.

1.5 This paper looks into applying energy scale variations to the problem of inflation.

2 Cosmology Equations

2.1 Our starting point is that there is no dark matter and no dark energy and that the energy scale can vary from location to location.

2.2 The standard Friedmann Equation (Ryden, 2017) is:

$$\left(\frac{\dot{a}}{a}\right)^2 = H^2 = \frac{8\,\pi\,G}{3\,c^2}\left\{\varepsilon_b + \varepsilon_r + \varepsilon_{DM} + \varepsilon_\Lambda\right\} \tag{1}$$

where ε_b is the energy density of baryons (normal matter); ε_r the energy density of radiation; ε_{DM} the energy density of dark matter; ε_Λ the energy density of the cosmological constant, Λ.

2.3 Following JoKe12 (2017) the Friedmann Equation can be written as

$$\left(\frac{\dot{a}}{a}\right)^2 = H^2 = \frac{8\,\pi\,G}{3\,c^2}\,\gamma\left\{\varepsilon_b + \varepsilon_r\right\} \tag{2}$$

where γ is a dimensionless number, the energy scale factor, which defines the effect of the energy scale varying from location to location. Gravity is a non-local effect in the sense that it depends on matter (and other forms of energy) at remote locations. Hence the inclusion of γ here; it can be considered as a factor that accounts for non-local effects.

2.4 Following JoKe12 (2017 and based on Ryden 2017), the equations for cosmology can be listed as follows.

2.5 The Friedmann Equation, equation (4), is

$$\left(\frac{\dot{a}}{a}\right)^2 = H^2 = \frac{8\,\pi\,G}{3\,c^2}\,\varepsilon\,\gamma \tag{3}$$

2.6 The Equation of State is

$$P = w\,\varepsilon \tag{4}$$

2.7 The Fluid Equation is

$$\frac{\dot{\varepsilon}}{\varepsilon} + 3\,(1+w)\,\frac{\dot{a}}{a} = 0 \tag{5}$$

2.8 The Acceleration Equation is

$$\left(\frac{\ddot{a}}{a}\right) = -\frac{1}{2}\left(\frac{\dot{a}}{a}\right)\left\{(1+3\,w)\left(\frac{\dot{a}}{a}\right) - \left(\frac{\dot{\gamma}}{\gamma}\right)\right\} \tag{6}$$

3 Radiation Only Universe

3.1 Models of the Universe show that radiation was dominant over matter immediately after the Big Bang. In our scenario of a flat Universe dominated by radiation the equations are:

3.2 The Friedmann Equation, equation (3), is unchanged

$$\left(\frac{\dot{a}}{a}\right)^2 = H^2 = \frac{8\,\pi\,G}{3\,c^2}\,\varepsilon\,\gamma \tag{7}$$

3.3 The Equation of State, equation (4), is

$$w = \frac{1}{3} \tag{8}$$

3.4 The Fluid Equation, equation (5), is

$$\frac{\dot{\varepsilon}}{\varepsilon} + 4\,\frac{\dot{a}}{a} = 0 \tag{9}$$

3.5 The Acceleration Equation, equation (6), is

$$\left(\frac{\ddot{a}}{a}\right) = -\frac{1}{2}\left(\frac{\dot{a}}{a}\right)\left\{2\left(\frac{\dot{a}}{a}\right) - \left(\frac{\dot{\gamma}}{\gamma}\right)\right\} \tag{10}$$

3.6 We look for a solution of equation (10) where both $\boldsymbol{a}$ and $\boldsymbol{\gamma}$ depend on time raised to some power, that is

$$a \propto t^r \tag{11}$$

and

$$\gamma \propto t^s \tag{12}$$

3.7 Feeding these into equation (10) leads to the result

$$r = \frac{s+2}{4} \tag{13}$$

3.8 The expansion of the Universe, equation (11), now becomes

$$\left(\frac{a}{a_0}\right) = \left(\frac{t}{t_0}\right)^{\left(\frac{s+2}{4}\right)} \tag{14}$$

where $a = a_0$ when $t = t_0$.

3.9 Differentiating equation (14) gives the rate of expansion

$$\left(\frac{\dot{a}}{a_0}\right) = \left(\frac{s+2}{4\,t_0}\right)\left(\frac{t}{t_0}\right)^{\left(\frac{s-2}{4}\right)} = H \tag{15}$$

3.10 The Hubble parameter H_0 is defined by $t = t_0$. Equation (15) can be inverted to give the age of the Universe

$$t_0 = \left(\frac{s+2}{4}\right)\frac{1}{H_0} \tag{16}$$

3.11 The behaviour of the energy density follows from equation (9)

$$\left(\frac{\varepsilon}{\varepsilon_0}\right) = \left(\frac{a}{a_0}\right)^{-4} \tag{17}$$

So the energy density depends, as it must for radiation, on the inverse fourth power of the volume.
And from equation (14)

$$\left(\frac{\varepsilon}{\varepsilon_0}\right) = \left(\frac{t}{t_0}\right)^{-(s+2)} \tag{18}$$

3.12 Differentiating equation (15) gives the acceleration of the Universe as

$$\left(\frac{\ddot{a}}{a_0}\right) = \left(\frac{s+2}{4\,t_0}\right)\left(\frac{s-2}{4\,t_0}\right)\left(\frac{t}{t_0}\right)^{\left(\frac{s-6}{4}\right)} \tag{19}$$

3.13 In cosmology the deceleration parameter q_0 is defined as

$$q_0 = -\left(\frac{\ddot{a}\ a}{\dot{a}^2}\right)_{t=t_0} \tag{20}$$

Equations (14), (15), (20) then lead to

$$\boldsymbol{q_0} = -\left(\frac{\boldsymbol{s-2}}{\boldsymbol{s+2}}\right) \tag{21}$$

4 Some Solutions

4.1 We can now consider the behaviour of the Universe using equations (19), (16) and (21) for different values of $\boldsymbol{s}$.

4.2 $\boldsymbol{s = 0}$

This represents a Universe with no energy scale variations and must give the standard result of a flat radiation-only cosmology.

$$\left(\frac{\ddot{a}}{a_0}\right) = -\frac{1}{t_o^2}\left(\frac{t}{t_0}\right)^{-\left(\frac{3}{2}\right)} < 0 \tag{22}$$

$$t_0 = \frac{1}{2}\frac{1}{H_0} \tag{23}$$

$$q_0 = +1 \tag{24}$$

This Universe is decelerating and these are the standard cosmological results.

4.3 $\boldsymbol{s = 1}$

$$\left(\frac{\ddot{a}}{a_0}\right) = -\frac{3}{4\,t_o^2}\left(\frac{t}{t_0}\right)^{-\left(\frac{5}{4}\right)} < 0 \tag{25}$$

$$t_0 = \frac{3}{4}\frac{1}{H_0} \tag{26}$$

$$q_0 = +\frac{1}{3} \tag{27}$$

This Universe is also decelerating.

4.4 $s = 2$

$$\left(\frac{\ddot{a}}{a_0}\right) = 0 \tag{28}$$

$$t_0 = \frac{1}{H_0} \tag{29}$$

$$q_0 = 0 \tag{30}$$

There is no acceleration; the Universe is coasting and expanding at a constant rate.

4.5 $s = 3$

$$\left(\frac{\ddot{a}}{a_0}\right) = +\frac{5}{16\, t_o^2}\left(\frac{t}{t_0}\right)^{-\left(\frac{3}{4}\right)} > 0 \tag{31}$$

$$t_0 = \frac{5}{4}\frac{1}{H_0} \tag{32}$$

$$q_0 = -\frac{1}{5} \tag{33}$$

This Universe is accelerating.

4.6 $s = 6$

$$\left(\frac{\ddot{a}}{a_0}\right) = +\frac{2}{t_o^2} = constant \tag{31}$$

$$t_0 = \frac{2}{H_0} \tag{32}$$

$$q_0 = -\frac{1}{2} \tag{33}$$

This Universe is accelerating.

4.7 $\boldsymbol{s = 10}$

$$\left(\frac{\ddot{a}}{a_0}\right) = +\frac{6}{t_o^2}\left(\frac{t}{t_0}\right) > 0 \tag{34}$$

$$t_0 = \frac{3}{H_0} \tag{35}$$

$$q_0 = -\frac{2}{3} \tag{36}$$

This Universe is accelerating.

4.8 $\boldsymbol{s = 46}$

$$\left(\frac{\ddot{a}}{a_0}\right) = +\frac{132}{t_o^2}\left(\frac{t}{t_0}\right)^{10} > 0 \tag{37}$$

$$t_0 = \frac{12}{H_0} \tag{38}$$

$$q_0 = -\frac{11}{12} \tag{39}$$

This Universe is accelerating.

4.9 $\boldsymbol{s = 4\,N}$ where $\boldsymbol{N \gg 1}$

$$\left(\frac{\ddot{a}}{a_0}\right) = +\frac{N^2}{t_o^2}\left(\frac{t}{t_0}\right)^{N} > 0 \tag{40}$$

$$t_0 = \frac{N}{H_0} \tag{41}$$

$$q_0 = -1 \tag{42}$$

This Universe is accelerating. The acceleration is a power law and not an exponential as in standard inflation.

5 Inflation

5.1 There appears to be an overwhelming consensus amongst the scientific community that immediately after the big bang there was a period of inflation during which the Universe expanded exponentially by at least 26 orders of magnitude (Ryden, 2017; Weinberg, 2008). Inflation explains three major problems of cosmology: the flatness problem; the horizon problem; the monopole problem.

5.2 We consider the case where our energy scale parameter has the modest value of $s=10$, as set out in section 4.7.

5.3 Equation (14) becomes:

$$\left(\frac{a}{a_i}\right) = \left(\frac{t}{t_i}\right)^3 \tag{43}$$

where the i subscript indicates the start of inflation.

5.4 For convenience we look for an increase of 27 orders of magnitude rather than the 26 of section 5.1 above. Equation 43 then becomes:

$$10^{27} = \left(\frac{a_f}{a_i}\right) = \left(\frac{t_f}{t_i}\right)^3 \tag{44}$$

or

$$10^9 = \left(\frac{t_f}{t_i}\right) \tag{45}$$

where the f subscript indicates the finish of inflation

5.5 So if inflation began at $t_i = 1$ second then it would need to finish at $t_f = 10^9$ seconds or approximately 32 years.
And if inflation began at $t_i = 10$ seconds then it would need to finish at $t_f = 10^{10}$ seconds or around 320 years.
Similarly for much shorter (earlier) times.

6 Discussion

6.1 The above sections demonstrate that energy scale variations can give rise to a period of power law inflation during the very early Universe.

6.2 The details of the inflation period have not been investigated. However, there are clearly requirements for nucleosynthesis that have to be met, including the conditions for the formation of helium and other elements. These have not been considered here.

6.3 The standard Friedmann Equation of cosmology, without a dark energy term, cannot give rise to an accelerating Universe, only decelerating Universes. Our introduction of variations in the energy scale get round this restriction and allow for accelerating Universes.

6.4 We still lack any understanding of the physical principles behind variations in the energy scale. We are at the stage of having an explanation of 'how' the Universe might behave, not 'why' the Universe has to behave this way.

6.5 Our stance is not that energy scale variations exist. Our stance is simply that one way of looking at the Universe is to assume that variations of the energy scale occur and then see what follows from this assumption.

7 References

JoKe1. "On the variation of the energy scale: an alternative to dark matter". 2015. www.varensca.com

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