

## Research Article

Bernard G. Colenbrander\* and Willem S. Hulscher

# Variable $G$ versus the Accelerated Expansion of the Universe

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**Abstract:** It is shown that the hypothesis of permitting variability of the Newtonian constant  $G$ , increasing with the local density of dark matter, implies that there is no need for the introduction of a cosmological constant or accelerated expansion of the universe. A higher value of  $G$  in the younger universe leads to an enhanced redshift of the spectra from e.g. supernovae, which results in an estimation of a larger distance and magnitude. Interpreting relevant astronomical observations in terms of both effects leads remarkably to a linear relationship between the redshift and the magnitude of the supernovae throughout the history of the universe. Furthermore it is shown, that from CMB measurements, no reliable conclusions can be drawn about the structure and geometry of the universe. It is concluded that, if the hypothesis survives further tests, no valid evidence is available that would point to an accelerated expansion of the universe and therefore it is not necessary to assume the existence of dark energy.

**Keywords:** supernova, redshift, accelerated expansion, gravitational constant, inert mass, Chandrasekhar limit, dark energy, cosmological constant, CMB

## 1 Introduction

In our recent paper (Colenbrander and Hulscher 2017) we revealed a relationship between the Newtonian constant  $G$  and the density of dark matter. We concluded that the Einstein field equations can be rewritten in their original form without the cosmological constant  $\Lambda$ , because  $G$  depends on place and time. Our hypothesis is that  $G$  depends on the local density of dark matter, which varies with the local mass concentration. With time, the dark matter density falls, as does  $G$ , because of the expanding universe.

We should realize that the determination of any mass entity  $M$  in the universe results from the determination of the product of  $G$  and  $M$ . This is therefore a (weakly) non-linear theory of gravitation. As  $G$  appears to be not a universal constant of nature but varies with place and time, the value of the gravitational mass  $M$  needs appropriate correction. This applies to all types of masses, e.g. from the mass of planets to stars and galaxies.

In particular it applies to supernovae with their associated redshifts, which are used as standard candles for cosmological measurements. Given the equivalence of gravitational and inertial mass, a higher density of dark mat-

ter also influences the inertial mass of electrons orbiting around a nucleus, with their associated spectra. We examine both corrections under weakly non-linear conditions which have implications for the studies of Perlmutter *et al.* (1998) and of Riess *et al.* (1998) on the redshifts of supernovae, on the basis of which it had been concluded that the universe is expanding at an accelerated rate.

## 2 Gravitational time dilation and inert mass

In order to understand the effects of the density of dark matter on atomic spectra we refer to Einstein's thought experiment with a clock placed far from the earth and an identical clock on the earth. According to general relativity the rate of the clock on the earth is slower than the rate of the clock in space. Many observations confirm this phenomenon of gravitational time dilation, for example as applied to the system of global positioning (GPS) (Ashby 2006).

A clock, which in fact is a harmonic oscillator, can be represented by a spring-mass system. The period  $T$  of the oscillator depends on the inert mass  $m_{\text{inert}}$  and the force constant  $k$  of the spring:

$$T = 2\pi \sqrt{\frac{m_{\text{inert}}}{k}}. \quad (1)$$

**Corresponding Author: Bernard G. Colenbrander:** Beekshuis, Winterswijk, The Netherlands; Email: b.g.colenbrander@gmail.com  
**Willem S. Hulscher:** Beekshuis, Winterswijk, The Netherlands

On the earth the density of dark matter and so the gravitational constant  $G$  are larger than in space. Therefore the inert mass of the oscillator of the clock on the earth is larger than the oscillator mass of the clock in free space.

Because of a larger inert mass of the oscillator the period  $T$  is larger, so the rate of the clock on the earth is slower than the rate of the clock in space. Using our hypothesis the inert mass of an oscillator depends on the density of dark matter and so on the value of  $G$  on that place. This characteristic has implications for the inert mass of an electron orbiting around a nucleus and hence for the spectra of atoms.

### 3 $G$ and the change of spectra

In a distant galaxy the higher density of dark matter had consequences for the frequencies of the emitted spectra. The following formula applies for the frequencies  $f$  of the spectra of a hydrogen atom:

$$f = \frac{me^4}{8\epsilon_0^2 h^3} \left( \frac{1}{j^2} - \frac{1}{k^2} \right), \quad (2)$$

$m$  is the mass and  $e$  is the electric charge of the electron.  $\epsilon_0$  is the permittivity of free space and  $h$  is Planck's constant.  $j$  and  $k$  are integers describing the lower and the upper stationary states of the atom.

The inert mass of an electron increases when the dark matter density increases, so the energy of a quantum jump between two certain states increases and so the wavelength  $\lambda_{source}$  of the emitted radiation decreases. For the redshift  $z$  the following formula applies:

$$z = \frac{\lambda - \lambda_{source}}{\lambda_{source}} \quad (3)$$

in which  $\lambda$  is the measured wavelength.

As the wavelength emitted by an atom in a distant galaxy is smaller than the wavelength emitted by an identical atom in today's laboratories, the measured redshift  $z$  must be corrected.

### 4 $G$ and the expansion of the universe

Type Ia supernovae offer an unique opportunity for distance measurements. Data from these measurements have suggested that the expansion of the universe is accelerating. Acceleration implies an energy and this energy is generally called dark energy.

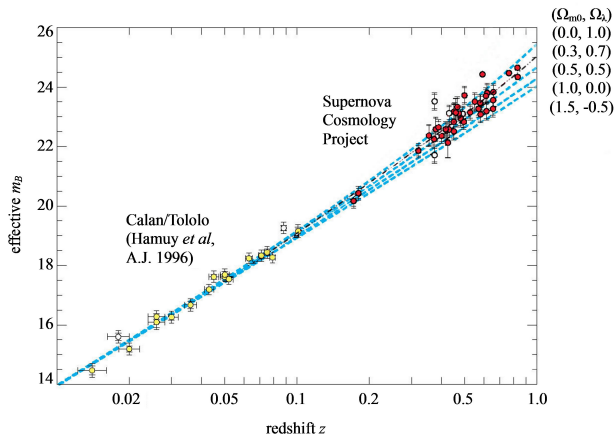
As we know, type Ia supernovae derive their energy from fusion of the nuclei in the interior of a white dwarf. The white dwarf accretes matter from a companion star which leads to a steadily increasing mass. Its density increases due to gravity and so its pressure and temperature increase. When the mass of the white dwarf approaches the Chandrasekhar limit, nuclear fusion starts, which disrupts the star and causes the supernova. The pressure inside the white dwarf, as caused by the gravitational force, depends on the product  $GM$  of the gravitational constant  $G$  and the mass  $M$  of the dwarf. When the mass  $M$  reaches the critical value of the Chandrasekhar mass  $M_{Ch} = 1.4 M_{Sun}$ , the dwarf explodes.

It is generally assumed that every white dwarf of type Ia in the universe is bound by the same critical mass. However, we argue that in the younger universe  $G$  had a higher value than later because of a higher density of dark matter, and so the critical mass of a dwarf in that period was less than  $1.4 M_{Sun}$ . A supernova based on a mass  $M < 1.4 M_{Sun}$  produces less energy than a supernova with  $1.4 M_{Sun}$ , because energy is coupled to mass. So this smaller supernova seems to be farther away than it actually is. If for the supernova the proper value of  $G$  is used, the distance to that supernova will turn out to be smaller. As a result the cluster of points of the Supernova Cosmology Project, *i.e.* the cluster of red dots in Figure 1 as adapted from Perlmutter, moves down in the direction of the line of the linear expansion.

Furthermore, in section 3 above we showed that a larger value of  $G$  increases the energy of emitted photons. That means that for a supernova at a larger distance the wavelength  $\lambda_{source}$  is lower and so the real redshift  $z$  is larger. If the proper value of  $G$  is applied, the actual redshift will be larger. This means the cluster of points of the Supernova Cosmology Project moves horizontally to the right in the direction of the line of linear expansion.

In Figure 1 a Hubble diagram published by Perlmutter *et al.* (1998) is plotted with horizontally the redshift  $z$  versus vertically the magnitude  $m_B$ . The measured points from Calan/Tololo follow the straight line of linear expansion, marked  $(\Omega_M, \Omega_\Lambda) = (1.0, 0.0)$ , but the points measured in the Supernova Cosmology Project, *i.e.* the red dots, deviate from this line of linear expansion. The deeper in the universe, the more this deviation seems to be. As we have explained, the effect can be understood because deeper in the universe the value of  $G$  is larger.

Both corrections, on the emitted radiation as well as on the critical mass, cause the cluster of points in the graph to move closer to the line of linear expansion. That implies there is no case for an accelerated expansion of the universe. For a detailed quantitative analysis of the sug-



**Figure 1.** Horizontal: the redshift  $z$ , which is a measure for the velocity of a supernova. Vertical: the magnitude  $m_B$  of supernovae, which is a measure for the distance.

gested linearity the local value of  $G$  at the supernova needs to be known. Without this information it cannot be concluded from the measurements that the universe would be expanding at an accelerated rate.

## 5 $G$ and the Hubble diagram of type-Ia supernovae

In 2001 Gaztañaga *et al.* (2001) showed that the deviation of the Hubble diagram of supernovae type-Ia can be understood by assuming either an accelerated expansion of the universe or a steady expansion with a decreasing  $G$  value in time. They realised that the latter implies assuming a higher value of  $G$  in the younger universe. This would reduce the Chandrasekhar mass via the relation  $M_{Ch} \propto G^{-3/2}$  and that would reduce the luminosity of the supernovae.

In order to arrive at a lower luminosity of a distant supernova (redshift  $z = 0.5$ ) by  $\Delta m = 0.2$ , they calculated a value of  $G = 1.13 G_0$ , in which  $G_0$  is the local value. This change, an increase of  $G$  of 13%, was rejected by the authors because it conflicted with the prevailing understanding of gravity. However in our theory an increase of 13% is not surprising. The measured variations of  $G$  on earth, due to the asymmetrical dark matter distribution as caused by the non-spherical mass concentration of the earth, imply a spread  $\Delta G/G_0 = 0.0019$  from a pole to the equator (Colenbrander and Hulscher 2017). So, a very small variation in mass, resulting in a variation in the dark matter density, causes already a change of  $G$  of about 0.19%. Because the mass of a supernova is in the order of a sun mass, which is

about 300,000 times the mass of the earth, the dark matter density around a supernova can only be much higher than on the earth and so the value of  $G$  at that the supernova will be much higher than  $G_0$ .

## 6 Variable $G$ and the Cosmic Microwave Background Radiation

Because CMB is considered to be an important instrument for studying the composition and the geometry of the universe, we raise the question whether there is a relation between  $G$  and CMB

It is known that about 380,000 years after the big bang the universe had grown to one thousandths of its current size. At that time the temperature of the gas had decreased sufficiently for protons to capture free electrons and become atoms. Hence, photons were no longer scattered by charged particles and could travel freely in all directions. This moment of recombination is mainly determined by the ionisation energy of hydrogen,

$$E_{ion} = \frac{me^4}{8\epsilon_0^2 h^2} \quad (4)$$

$m$  is the mass and  $e$  the electric charge of the electron.  $\epsilon_0$  is the permittivity of free space and  $h$  is Planck's constant.

At the moment of recombination the density of the universe was much higher than today and according to our hypothesis the density of dark matter was also much higher. As we have stated in section 3, the inert mass of an electron is larger when the dark matter density is larger, so the ionisation energy of hydrogen at the moment of recombination was higher than today. That means that recombination could occur at a higher temperature, thus took place earlier in time than what is generally believed.

The temperature variations of the radiation of the CMB are caused by vibrations of waves in the very hot plasma of that time. Alternation of compression and rarefaction results in hot and cold spots in the plasma. The pattern of hot and cold spots induced by this so called Baryonic Acoustic Oscillations is frozen into the CMB map. The frequency of the emitted radiation is then diminished to microwave radiation. At the moment of emitting the radiation by the hotter and colder spots the value of  $G$  was much higher than today, so the emitted wavelengths were smaller than the wavelengths emitted by an identical atom in today's laboratories [section 3]. So the measured redshift is larger and so the distance. This fact is consistent with the earlier occurrence of the event of recombination, as we have stated above.

The baryonic acoustic oscillations can be interpreted as a spring-mass system, in which the spring is the pressure of the radiation and the mass is provided by the baryons. The frequency of the baryonic acoustic oscillations determines the distances between the hot spots. A higher frequency means a smaller wavelength so the distance between two hotspots is smaller. Because the value of  $G$  was higher than today, the plasma was more compressed and therefore the spring constant  $k$  was higher. But for the same reason the inert mass was higher, so it is not clear how the frequency is changed by a higher value of  $G$ . Therefore there is uncertainty about the distances between the hotspots and so about the starting position of the growing galaxy formations.

So, for two reasons, the so called “reliable observations” of clusters of galaxies are not very certain: the starting position of the clusters appears unclear and the emitted photons had a higher energy. As a result the CMB measurements are less revealing than they are generally supposed to be and hence do not provide a reliable support for the theory of an accelerated expanding universe.

## 7 Variation of fundamental physical constants and the recombination time

The Planck Collaboration Group (Planck Collaboration: Ade *et al.* 2015) showed that a variation of the fundamental physical constants like the mass of an electron  $m_e$  and the fine structure constant  $\alpha$  would affect the recombination history of the universe and cause an imprint on the cosmic microwave background angular power spectrum. By modelling they found that a larger value of the constants  $m_e$  and  $\alpha$  makes the recombination happen earlier and has an influence on the shape of the CMB power spectrum. In section 6 we presented a theory in which the inert mass of an electron actually varies because of the increased density of the dark matter. We explained why this variation does change the recombination time and the shape of the CMB spectrum. These changes are in accordance with the findings of the Planck group. Moreover our theory predicts a higher energy of the emitted photons that supports the larger interval from today to the time of recombination.

## 8 Conclusions

The peculiar deviation of the Hubble diagram of type-Ia supernovae can be understood by applying to the measurements appropriate corrections that result from a decreasing  $G$  value in time. This implies that such deviation does not point to an accelerated expansion of the universe. Also measurements of the CMB do not provide reliable arguments for an accelerated expansion of the universe. Without such acceleration there is no need to assume the existence of dark energy and to introduce a cosmological constant  $\Lambda$ .

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