Self Creation Cosmology An Alternative Gravitational Theory

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Abstract

A question is raised about the premature acceptance of the standard cosmological model, the 'ΛCDM' paradigm; the non-metric, or semi-metric, theory of Self Creation Cosmology is offered as an alternative and shown to be as equally concordant as the standard model with observed cosmological constraints and local observations. In self-creation the Brans Dicke theory is modified to enable the creation of matter and energy out of the self contained gravitational and scalar fields; such creation is constrained by the local conservation of energy so that rest masses vary whereas the observed Newtonian Gravitation 'constant' does not. As a consequence there is a conformal equivalence between self-creation and General Relativity in vacuo, which results in the predictions of the two theories being equal in the standard tests. In self-creation test particles in vacuo follow the geodesics of General Relativity. Nevertheless there are three types of experiment that are able to distinguish between the two theories. There are also other local and cosmological observations that are readily explained by self-creation, such as the anomalous sunwards acceleration of the Pioneer spacecraft and a secular spinning up of the Earth’s rotation that both ‘coincidentally’ echo Hubble’s constant. Moreover, the most significant feature of self-creation is that it is as consistent with cosmological constraints in the distant supernovae data, the Cosmic Microwave Background anisotropies and primordial nucleo-synthesis, as the standard paradigm. Unlike that model, however, it does not require the addition of the undiscovered physics of Inflation, dark non-baryonic matter, or dark energy. Nevertheless it does demand an exotic equation of state, which requires the presence of false vacuum energy at a moderate density determined by the field equations. Consequently it is able to interface gravitation and quantum theories without creating a 'Lambda' problem. In self-creation there are two frames of interpretation of observational data, which depend on whether energy or energy-momentum is to be conserved and whether photons or atoms respectively are chosen as the invariant standards of measurement. In the former frame the universe is stationary and eternal with exponentially shrinking rulers and accelerating atomic clocks, and in the latter frame the universe is freely coasting, expanding linearly from a Big Bang with rigid rulers and regular atomic clocks. A novel representation of space-time geometry is suggested. As
the theory is readily falsifiable it is recommended that all three of the definitive experiments be performed at the earliest opportunity.

Note

The speed of light \textit{in vacuo} is unity in this paper, except when predictions are to be compared to observation, when the speed of light will be explicitly designated as $c$.

1 Introduction

The present standard cosmology based on General Relativity (GR) is known as the $\Lambda$CDM model, where ‘$\Lambda$’ refers to the dark energy, or the cosmological constant, and ‘CDM’ to the cold dark matter that are believed to pervade the universe. The general consensus, [1], [2], is that the detailed observational verification of this $\Lambda$CDM model, in which the mass of the universe consists of 23 per cent dark matter, 73 per cent dark energy and just 4 per cent ordinary matter, has been robustly established and there is little purpose in exploring possible alternatives. However, it is always healthy for the scientific process to have heterodox theories against which the standard theory may be tested. The problem in cosmology has been to find such a theory that not only matches General Relativity in all the standard observations, but also raises questions that lead to further experiments against which both theories may be tested. One possible alternative, first published in 2002, is described in this paper; it is the theory of Self Creation Cosmology (SCC) [3].

1.1 Questions raised by the Standard Model

The $\Lambda$CDM model has gained strong support from the peaks in the WMAP and Boomerang CMB data as well as the S/N Ia Hubble diagram. As such, this recent period has been hailed as the ‘era of precision cosmology’ with the general acceptance that the particular values of the cosmological constraints mentioned above have been established beyond reasonable doubt.

Let us however examine the present problems that have been identified with the theory. The hypothesis of Inflation was proposed in the 1970’s in order to escape the density, smoothness and horizon problems of GR cosmology; this led to the present $\Lambda$CDM model. This model suggests that the false vacuum energy on which Inflation depended has not entirely disappeared but continues as a remnant to constitute a significant cosmological component called dark energy. The existence of such a false vacuum energy is consistent with cosmic acceleration; nevertheless it is difficult to explain why it seems to have been fine-tuned to at least one part in $10^{102}$. In addition, the standard paradigm requires the existence of cold dark matter together with dark energy and Inflation, all of which depend on physics as yet undiscovered by laboratory science even after twenty years of intensive research. Inexplicably, the densities of these ‘dark’ entities are not only approximately equal to each other but also roughly equal.
to the baryon density. Whereas it is always possible to explain such improbable coincidences by appealing to the anthropic principle, the explanatory power of a theory, such as Inflation, is questionable if it can only account for an original coincidence by the introduction of several new ones.

There are other potential problems. In the standard ΛCDM paradigm the SNIa Hubble diagram, mentioned above, requires a value for the vacuum energy density that is so small that it is unstable to quantum corrections. This vacuum energy may alternatively be interpreted as a small positive cosmological constant; however, as such it is incompatible with the generally accepted Superstring models that may provide the basis for a quantum gravity theory. These theories, which compactify higher dimensions, prefer models with a negative or zero cosmological constant.

It seems that the ΛCDM also has astrophysical problems in predicting galaxy mass profiles that have a too pronounced cusp at small scales and a too steep galaxy luminosity function. Although these observations are not 'clean' in the sense that they may suffer from systematic errors that may explain the anomalies; for example the SNIa Hubble diagram may require evolutionary corrections and the precision of the CMB power spectrum may still be compromised by foreground contamination from the epoch of re-ionisation at $z = 15$; nevertheless they are also theory dependent. It may therefore be the theoretical basis of this analysis, GR, or possibly the cosmological topology, which requires modification.

In conclusion, the rumours of the 'end of cosmology' may well be premature.

1.2 Other Related Anomalies?

There are also other interesting observations closer to hand that may be connected to cosmological effects but which have generally not been related to fundamental physics. For example the Pioneer spacecraft appear to have an anomalous sunward acceleration [4], [5]. This acceleration may have several components, and there may be several possible explanations for each component, however, as it has been observed a number of times, the excess over the General Relativity acceleration:

$$a_P = (8.74 \pm 1.3) \times 10^{-8} \text{ cm/sec}^2$$

is equal to $cH$ (where $H$ is Hubble’s constant) if $H = 87 \text{ km/sec}^{-1}/\text{Mpc}$. Therefore this anomaly might be cosmological in nature and explained by a non-standard gravitational theory.

A second anomaly as reviewed by Leslie Morrison and Richard Stephenson, [6], [7], arises from the analysis of the length of the day from ancient eclipse records. It is that in addition to the tidal contribution there is a long-term component acting to decrease the length of the day, which equals:

$$\triangle T/\text{day/cy} = -6 \times 10^{-4} \text{ sec/day/cy.}$$

This component, which is consistent with recent measurements made by artificial satellites, is thought to result from the decrease of the Earth’s oblateness...
following the last ice age. Although this explanation certainly merits careful consideration, and it is difficult to separate the various components of the Earth’s rotation, it is remarkable that this value of $\Delta T/\text{day/cy}$ is equal to $H$ if $H = 67 \text{km.sec}^{-1}/\text{Mpc}$. The question is: why should this spinning up of the Earth’s rotation have a natural time scale equal to the age of the universe rather than the natural relaxation time of the order of that of the Earth’s crust or the periodicity of the ice ages? This anomaly also may therefore be cosmological rather than geophysical in nature. If this is the case then again it is a phenomena not explicable by the standard theory.

A third anomaly, which arises from the analysis of the residues of planetary longitudes, reveals that the Gravitational constant appears to be varying at a rate also of the order of Hubble’s constant. An analysis [8] rendered a problematic value for a variation in $G$:

$$\frac{\dot{G}}{G} \approx + (4 \pm 0.8) \times 10^{-11} \text{yr}^{-1}$$

with a caveat that the sign might be reversed. As this value is equal to $H$ if $H = 38 \text{km.sec}^{-1}/\text{Mpc}$, then it too may be cosmological in nature. GR predicts a null result for this analysis.

If these are indeed three observations of Hubble’s constant, then their values have a spread typical of other determinations of $H$ with an average of $H = 64 \text{km.sec}^{-1}/\text{Mpc}$ in good agreement with more orthodox methods. Although there may well be other explanations for these anomalies it is remarkable that all three approximate Hubble’s constant. Although these three observations themselves may well have non-cosmological explanations, and individually do not seriously question GR, it will be seen that they are all actually predicted by SCC.

## 2 The Self Creation Alternative

### 2.1 Theory development 1. Mach’s Principle and creation from the Scalar Field

The new SCC is offered as an alternative to the standard paradigm. It has not only been shown to be concordant with cosmological observations and the standard tests of GR, but it also provides a ready explanation for the anomalies described above.

The SCC theories, which were first published in 1982 [9], explored modifications of the Brans Dicke theory (BD) [10] in which the conservation of energy-momentum was relaxed, and the equivalence principle consequently violated, to allow mass creation. The BD theory fully incorporated Mach’s principle into GR by the inclusion of an inertial scalar field while retaining the equivalence principle. As a result, in all the SCC theories mass creation originates from the self-contained gravitational and scalar fields.
Although BD incorporates both the equivalence principle and Mach’s principle the two might be seen to be fundamentally mutually incompatible. Mach’s principle suggests that inertial frames of reference should be coupled to the distribution of mass and energy in the universe at large. Therefore that frame of reference in which the universe as a whole is at rest might be considered to be a preferred ‘frame’, in which total energy is conserved, in contradiction to the spirit of the equivalence principle. Indeed such a preferred frame of reference does appear to exist; it is that in which the Cosmic Background Radiation (CBR) is globally isotropic. Furthermore some also argue that Mach’s principle requires the gravitational parameter, G, to be determined by the large-scale structure of the universe and not equal to some arbitrary constant.

The original SCC paper postulated two theories; the first ‘toy theory’ was seen to be experimentally non-concordant with the Einstein equivalence principle (EEP), and the second was an early version of the present theory.

In order to include Mach’s principle the SCC theories follow BD by coupling a scalar field that endows particles with inertia $\phi \approx \frac{1}{G}$ to the distribution of matter in the universe

$$\Box \phi = 4\pi \lambda T_M,$$  \hspace{1cm} (4)

where $\Box \phi = \phi^{\sigma}_{\sigma}$ is the d’Alembertian of $\phi$ (the covariant equivalent of the Laplacian $\nabla^2 \phi$), $T_M$ is the trace of the energy-momentum tensor describing all non-gravitational and non-scalar field energy and $\lambda$ is some undetermined coupling constant of the order unity. The addition of the scalar field opened up an extra degree of freedom, which is determined by $\lambda$. Its presence is recognised in the gravitational field equation that now takes the form

$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = \frac{8\pi}{\phi} [T_M{}_{\mu\nu} + T_{\phi \mu\nu}], \quad (5)$$

where $T_M{}_{\mu\nu}$ and $T_{\phi \mu\nu}$ are the energy momentum tensors describing the matter and scalar fields respectively. In the second theory the scalar field was minimally coupled to the metric and therefore only interacted with the material universe by determining the gravitational coefficient $G$ hence the field equation became

$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = \frac{8\pi}{\phi} T_M{}_{\mu\nu}. \quad (6)$$

The 1982 paper has generated some interest (see [11]) over the last twenty years, however Brans [12] criticised this second theory because of the difficulty in defining the metric if photons no longer travel on (null)-geodesics. In BD and GR photons do travel on null-geodesics because of the equivalence principle, which leads directly to the energy-momentum conservation equation of those theories

$$\nabla_{\mu} T_M{}^{\mu}_{\nu} = 0. \quad (7)$$

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2.2 Theory development 2. The Principle of Mutual Interaction

In order to overcome Brans’ objection that photons should follow geodesic trajectories the latest SCC theory introduced a principle of mutual interaction (PMI). This principle states that the scalar field is a source for the matter-energy field if and only if the matter-energy field is a source for the scalar field, by coupling $\nabla_{\mu} T_{\mu \nu}^M$ to $T_M$, thus:

$$\nabla_{\mu} T_{\mu \nu}^M = f_{\nu} (\phi) \Box \phi = 4\pi f_{\nu} (\phi) T_M, \quad (8)$$

so that for an electro-magnetic field, which is trace-free, $T_{em} = 0$,

$$\nabla_{\mu} T_{em \mu \nu} = 4\pi f_{\nu} (\phi) T_{em} = 4\pi f_{\nu} (\phi) \left(3\rho_{em} - \rho_{em}\right) = 0 \quad (9)$$

thus restoring the path of a photon to a null-geodesic of the metric. As a consequence, although SCC is not a completely metric theory, it can be thought of as semi-metric, because photons do obey the equivalence principle, although particles do not.

The introduction of this principle, which allows creation in a controlled way, opened up a further degree of freedom represented by a second constant $\kappa$ that naturally appeared in this SCC equivalent of the conservation field equation. Calculation, [13], determined the function $f_{\nu} (\phi)$ above to be

$$f_{\nu} (\phi) = \frac{\kappa}{8\pi} \frac{\nabla_{\nu} \phi}{\phi}. \quad (10)$$

Consequently the conservation equation of the standard theory is replaced by what is called the creation field equation of the new SCC theory,

$$\nabla_{\mu} T_{\mu \nu}^M = \frac{\kappa}{8\pi} \frac{\nabla_{\nu} \phi}{\phi} \Box \phi. \quad (11)$$

This mass creation would manifest itself as a force density $f_{\nu}$ that acts throughout space-time on non-trace-free matter according to

$$f_{\nu} = \nabla_{\mu} T_{\mu \nu}^M = \frac{\kappa \lambda}{2} \frac{\nabla_{\nu} \phi}{\phi} T_M. \quad (12)$$

The question that immediately arises is, "Is not such a violation of the equivalence principle inconsistent with the experimental tests of the EEP that are accurate to within one part in $10^{-14}$?"

A remarkable feature of the PMI violation of the equivalence principle is that this 'scalar field force' acts in a similar fashion to the gravitational force. It is proportional to the product of the masses of two freely falling bodies and inversely proportional to the square of their separation. Thus, if this force exists, it would be convoluted with the Newtonian gravitational force and affect the value of the Newtonian gravitational constant in all Cavendish type experiments.

In accordance with the PMI, and as determined by the above creation field
equation, this force would affect particles but not photons. In Eötvös-type
tests of the EEP, the details of which will be examined below, it is found that
particles of different densities fall at the same rate to within one part in $10^{-17}$
and this violation would not have been detected by EEP experiments to date.
It is, however, possible to test the theory by investigating whether photons fall
at the same rate as particles or not. GR predicts that they should whereas
SCC predicts that they should not. Thus the theory suggests a new test of the
EEP. According to SCC, the effect of the scalar field force would be to produce
two separate values for the gravitational 'constant', one coupled to curvature
and the other measured in Cavendish type experiments, which are 'felt' by
relativistic and non-relativistic species respectively. We shall see below that the
experimental effect of this apparently gross violation of the EEP is less than
might be expected even on such projects as the LIGO gravity wave detectors.

2.3 Theory development 3. The Local Conservation of
Energy
As in BD the presence of the scalar field perturbs space-time, affects $\gamma$ (the
curvature produced per unit mass), and modifies the GR geodesics of freely falling
test particles. However, it was realised at an early stage of the development of
this theory that if $\kappa = 1/\lambda$ then the scalar field force had the effect of exactly
compensating for this perturbation of space-time. Subsequently it was realised
that this exact compensation was caused by the fact that this particular rela-
tionship of $\lambda$ and $\kappa$ created a conformal equivalence in vacuo between SCC and
canonical GR.

Furthermore it was seen that if a body was lifted against a gravitational field
and $\kappa = 1$, then the increase in rest mass would be exactly equal to the gain
in potential energy. Consequentially the theory was refined by the introduction
of another principle, that of the local conservation of energy. Accordingly, it
was postulated that a particle’s rest mass, $m$, should vary with gravitational
potential energy and therefore given by

$$m(r) = m_0 \exp \left[ \Phi_N(r) \right]. \quad (13)$$

Here $\Phi_N(r) = -\frac{G_NM}{r^2}$ is the dimensionless Newtonian potential and $m_0$ is the
particle’s rest mass at infinity. The force required to lift such a mass against a
gravitational field is

$$F_r = \frac{dE}{dr} = \left[ \frac{dm}{dr} \right] c^2 = \frac{G_NMm}{r^2}, \quad (14)$$
in accordance with Newtonian gravitational theory.

Mass and energy are defined at the Centre of Mass (CoM) of the gravitating
body. Whereas in BD inertial rest masses remain constant and the gravitational
'constant' $G_N$ varies, in SCC inertial masses vary and it is the observed New-
tonian constant that remains invariant. The constants $\lambda$ and $\kappa$ determine the
density of the scalar field and the 'rate' of creation respectively. If the local
conservation of energy and the invariance of $G_N$ are assumed then consistency requires both $\lambda$ and $\kappa$ to be unity. It was shown, [3], [13], that with these values photons ‘fall’ at one and a half times the gravitational acceleration experienced by particles, thereby providing one definitive test for the theory. As a consequence the theory is highly determined and makes specific predictions that render it easily falsifiable. However the conformal equivalence with canonical GR has the consequence that in all the standard tests *in vacuo* to date, the predictions of both SCC and GR are identical. Therefore the present tests that do verify GR with precision have not yet falsified SCC either.

In SCC, in which physical rulers and clocks vary with atomic masses, it is light that adopts the fundamental role of measuring the universe, in a similar, but more general, fashion to the theory of E.A.Milne’s Kinematic Relativity, [14], [15].

If the above introduction of both the local conservation of energy and Mach’s principle appears contrived, it is pertinent to remember that Einstein himself gave some consideration to these principles because he was concerned that they were not included in GR. They have been considered independently at various times since the publication of Einstein’s GR papers without much success, but in SCC they are considered together, and then they do produce a theory that is concordant with observation.

Nevertheless, as the conservation of energy-momentum is one of the most fundamental principles of modern physics we may well ask for what reason should it be abandoned? In order to formulate an answer to this question consider the fact that energy-momentum is a manifestly covariant concept, whereas energy is not, therefore according to the equivalence principle, and hence GR, it is energy-momentum that is locally conserved and not energy. This is because the total relativistic energy of a particle is relative to the inertial frame of reference in which it is measured. As the equivalence principle does not allow a preferred frame there is no definitive value for energy in any metric theory in which that principle holds. In the terminology of Emmy Noether’s 1918 paper [16], (see [17]), GR is an example of an improper energy theorem. A consequence of energy-momentum being conserved in a metric theory such as GR is that a particle’s rest mass is necessarily invariant. This is a result of rest mass being mathematically identical to the norm of the four-momentum vector.

In order to appreciate the problem with the conservation of energy-momentum at the expense of that of energy, let us consider, in a ‘gedanken’ or thought experiment, the four-momentum, $P^\mu$, of a projectile freely falling towards the Earth observed from an imaginary free falling laboratory at the Earth’s CoM. The four-momentum vector is composed of the mass-energy vector $P^0$ together with the momentum vector $P^i$ (where the superscripts $0 = \text{time}$ and $i = \text{space}$).

According to all metric theories the $P^\mu$ is conserved even as the projectile’s velocity towards the Earth increases and hence so does its momentum relative to our observer. As $P^\mu$, the momentum, increases and the norm $|P^\mu|$ remains constant then $P^0$, the total energy or ‘relativistic mass’ of the particle cannot be generally conserved; indeed it too steadily increases with the gain of kinetic energy. The problem is, however, that in the GR understanding of the situa-
tion no work is being done on or by the projectile, because it is freely falling along a geodesic converging with the Earth’s geodesic, so why should its energy increase? As a correction for this anomaly SCC proposes that the total energy of a freely falling body, on which no work is being done, should be invariant; a proposal that is implemented by the definition of rest mass above.

Consequentially in general SCC violates the equivalence principle, as it is energy and not energy-momentum that is conserved. Nevertheless the theory is still concordant with the present tests of the EEP. As a corollary gravitational red shift is not interpreted as a loss of energy by the photon but as an increase in rest mass of the apparatus used to measure it, [3]. The photon itself is of invariant energy and frequency.

As the energy and frequency of a photon is thus invariant when crossing curved space-time, a ‘standard’ photon, suitably defined, may be used as the unit measure for energy and hence mass, time and hence length. This system of measurement is called the Jordan energy frame [JF(E)] of the theory. Alternatively, a more usual system of measurement using atomic rulers and clocks, in which atomic rest masses are invariant and which conserves energy-momentum, may be defined; this is the Einstein frame (EF) of the theory.

3 The Conformal Transformation

Weyl’s hypothesis [18] was that a true infinitesimal geometry could only restrict the space-time manifold, $M$, to a class $[g_{\mu\nu}]$ of conformally equivalent Lorentz metrics and not just to a unique metric as in GR. These metrics are related through a conformal transformation given by

$$g_{\mu\nu} \rightarrow \tilde{g}_{\mu\nu} = \Omega^2 g_{\mu\nu}. \quad (15)$$

(Note: A tilde, $\tilde{n}$, signifies the Einstein frame and plain type, $n$, the Jordan frame.)

Recent interest that has sought to include a scalar field with the gravitational field has led to the development of a number of BD-type scalar field theories. These have a Jordan frame ($g_{\mu\nu}$) wherein $G$ varies and particle rest masses are constant, and an Einstein Frame ($\tilde{g}_{\mu\nu}$) wherein rest masses vary and it is $G$ that is constant. However Non Linear Gravity (NLG) theories have also been suggested that have constant rest masses in the Einstein frame. The Lagrangian densities of these NLG theories, the equations of which are cast in the same way as SCC, are given by:

$$L^{SCC}[g, \phi] = \frac{\sqrt{-g}}{16\pi} \left( \phi R - \frac{\omega}{\phi} \partial_{\mu} \phi \partial^{\mu} \phi \right) + L^{SCC}_{\text{matter}}[g, \phi] \quad (16)$$

in the Jordan frame and

$$L^{GR}[\tilde{g}, \tilde{\phi}] = \frac{\sqrt{-\tilde{g}}}{16\pi G_N} \left[ \tilde{R} - \left( \omega + \frac{3}{2} \right) \tilde{g}^{\mu\nu} \tilde{\nabla}_\mu \tilde{\phi} \tilde{\nabla}_\nu \tilde{\phi} \right] + \tilde{L}_{\text{matter}}[\tilde{g}] \quad (17)$$
in the Einstein frame.

In SCC the choice of frames is one of choice of a method of measurement; the question being, "What standard is used to define a unit of mass, length and time and how is that standard to be transported around the universe?" In the JF(E), in which energy is conserved, that standard is a standard photon; or in the EF, in which energy-momentum is conserved, it is a standard mass. The rest mass at a point \( x_\mu \) is defined in the JF(E) and the EF by

\[
m(x^\mu) = m_0 \exp[\Phi_N (x^\mu)] \quad \text{and} \quad \tilde{m}(\tilde{x}^\mu) = \tilde{m}_0 \text{ respectively.} \quad (18)
\]

As mass is conformally transformed according to \( m(x^\mu) = \Omega \tilde{m}_0 \), this duality may be obtained by defining the conformal transformation as

\[
\Omega = \exp[\Phi_N (x^\mu)]. \quad (19)
\]

In SCC both \( \lambda \) and \( \kappa \) are determined by the basic principles of the theory to be unity, and as \( \omega \) is given by

\[
\omega = \frac{1}{\lambda} - \frac{3}{2} - \kappa, \quad (20)
\]

therefore \( \omega = -\frac{3}{2} \). \quad (21)

With this conformal relationship, \( \Omega \), and value for \( \omega \), the conformal transformation \textit{in vacuo} of the SCC Jordan (Energy) frame

\[
L^{SCC}[g, \phi] = \frac{-g}{16\pi} \left( \phi R + \frac{3}{2\phi} g^{\mu\nu} \phi \nabla_\mu \phi \nabla_\nu \phi \right) + L^{SCC}_{\text{matter}}[g, \phi] \quad \text{becomes} \quad (22)
\]

\[
L^{SCC}[\tilde{g}] = \frac{-g}{16\pi G_N} \tilde{R} + \tilde{L}^{SCC}_{\text{matter}}[\tilde{g}] \quad \text{in the Einstein frame,} \quad (23)
\]

which is canonical GR.

This conformal equivalence with canonical GR explains why the relationship \( \lambda = \kappa^{-1} \) leads to the exact compensation for the perturbation of space-time by the scalar field force. Test particles follow the geodesics of GR \textit{in vacuo}. However when not \textit{in vacuo} this conformal equivalence breaks down and it is here that the theory differs from GR and may be tested against it. Tests that compare in the two theories the trajectories of geodesics \textit{in vacuo} will discover they are the same, whereas local measurements in the two theories of curvature, gravitational acceleration of photons, and local false vacuum densities, will differ.

In order that the reader may determine the theory’s predictions in contexts other than those explicitly treated in the SCC papers, the rule to be applied is that the curvature of space-time, and hence gravitational orbits and cosmological equations, are to be calculated in the JF(E); whereas atomic processes such as primordial nucleo-synthesis and the physics of matter are best calculated in the EF.
There has been a debate about scalar field theories in general regarding which frame is the physical frame, as both are problematic; the equivalence principle being violated in one frame and the scalar field energy being negative in the other. However in SCC both frames are physical, for not only is the equivalence principle preserved in the EF but also the scalar field energy is non-negative in the JF(E).

4 The Centre of Mass (CoM)

At the CoM of a system the function determining scalar field is stationary so that \( \nabla_\nu \phi = 0 \), therefore the creation equation,

\[
\nabla_\mu T^\mu_{\nu} = \frac{\kappa}{8\pi} \frac{\nabla_\nu \phi}{\phi} \Box \phi
\]

becomes

\[
\nabla_\mu T^\mu_{\nu} = 0 \tag{24}
\]

and the conservation equation is regained. Hence, at the unique location of the CoM of the system the energy-momentum tensor of matter is conserved with respect to covariant differentiation. Here the theory admits a ground state solution, the metric tensor reduces to that of Special Relativity, \( g_{\mu\nu} \rightarrow \eta_{\mu\nu} \), here the equivalence principle holds, even for a massive particle, and here a 'freely falling' physical clock records proper time and standards of mass, length, time and the physical constants, together with potential energy, retain their classical meaning. Distances can be measured by timing the echo of light rays (radar) using the freely falling clock and the metric may be properly defined. A 'standard' well-defined atom may emit a 'reference' photon mentioned earlier with well-defined and invariant energy, and hence frequency, which is subsequently transmitted across space-time.

Time is the fundamental measurement in both conformal frames. It is measured by the (invariant) frequency of the reference photon in the Jordan frame and by the 'Bohr' frequency of an atom (of invariant rest mass) in the Einstein frame. The speed of light is invariant in both. It is contended that gravitational, and hence cosmological, problems have to be solved in the Jordan frame and this is used throughout unless specifically stated otherwise.

The CoM is therefore selected as a preferred frame of reference by the requirement to locally conserve energy in the Jordan Frame. It divides out an 'absolute' time from the manifold thus selecting a "preferred foliation of space-time", to use Butterfield and Isham's expression [19], and such a preferred reference frame may provide insight into the problems at the gravitation and quantum theory interface. It might be pertinent to investigate this question in the future, but it is not followed up in this paper.

Over the past century physicists have wrestled with the question of absolute reference frames and hence absolute time. Einstein reacted against those of Lorentz and Fitzgerald by introducing the equivalence principle and the philosophy of 'no-preferred frames' of relativity theory. However quantum gravity has
struggled to reintroduce into gravitation such a preferred foliation of space-time, for that appears to be required by quantum considerations. In fact SCC unifies the conflicting requirements of GR and quantum physics because it contains a manifestly covariant Einstein frame and it also recognises a preferred foliation in its Jordan frame. However this preferred frame is not 'absolute' in the Newtonian sense of the word but rooted by Mach’s principle in the distribution of mass-energy within the universe.

5 Gravitational Red Shift

Consider a "gedanken", or thought, experiment in which a laboratory is constructed at the CoM of a spherical gravitating body connected to the surface by a radial tunnel through which photons and test particles may be projected 'in vacuo' to various maximum altitudes. The initial total energy or relative mass of each projectile as it is launched consists of its rest mass plus its kinetic energy, but later when it momentarily comes to rest at maximum altitude that kinetic energy vanishes. Thus, according to GR, the total energy appears to decrease even though no work has been done on or by the projectile while in freefall. The situation is aggravated when an allowance is made for the effect of curvature. The separation of events in space-time is described by the metric which is defined by \( d\tau^2 = -g_{\mu\nu}dx^\mu dx^\nu \) where the repeated lower and upper indices indicate summation over the four dimensions. It can be shown that if the times of arrival at \( x_1 \) of two adjacent wave fronts emitted from \( x_2 \) are considered, where \( (x_1) \) and \( (x_2) \) are mutually at rest in a gravitational field, then the emission and absorption frequencies of photons are described by the time dilation relationship

\[
\nu(x_2)/\nu(x_1) = \sqrt{[g_{00}(x_2)/g_{00}(x_1)]} .
\]

(25)

Therefore a photon emitted with frequency \( \nu \) at \( x_2 = r \) and received with frequency \( \nu_0 \) at \( x_1 = \infty \), will be observed to suffer the standard gravitational red shift of

\[
\nu(r) = \nu_0 \sqrt{-g_{00}(r)} .
\]

(26)

This is normally interpreted as a time dilation effect in which a clock deep in a gravitational potential well is observed from above to run slowly when compared with a clock at altitude, an effect that is well accepted and observed experimentally. But if it is assumed that the energy of the projectile in free fall is conserved, as determined in the CoM system of coordinates, then the rest mass is given by the expression, \[3\], \[13\],

\[
m(r) = m_0 \exp[\Phi(r)] \sqrt{-g_{00}(r)} .
\]

(27)

In this analysis the time dilation effect applies equally to the relative mass of a body as it does to photons projected between the same levels. Any measurement of gravitational red shift compares the energy of a photon (\( h\nu \)) with the physical mass-energy of the atom (\( m_p \)) it interacts with, therefore such a measurement
should be described, at the CoM, by the comparison of the two expressions above yielding:

\[ \frac{m(r)}{\nu(r)} = \frac{m_0 \exp \left[ \Phi(r) \right]}{\nu_0} . \]  

(28)

This relationship, which compares two observables, frequency and mass, includes the factor accounting for a difference in potential energy but not the one for time dilation. As these two factors are "coincidentally" equal in GR they have been readily confused. However the pertinent question is, "How is the above relationship to be interpreted?" That is, "How are mass and frequency to be defined and measured at different levels in any particular theory?" Experiments would naturally use the Einstein frame in which atomic masses are axiomatically defined to be constant as most apparatus is normally constructed out of atoms.

\[ m(r) = m_0 . \]  

(29)

Yet the problem in this frame is that photons mysteriously lose energy because the comparison of \( m(r) \) and \( \nu(r) \), yields,

\[ \nu(r) = \nu_0 \exp \left[ -\Phi(r) \right] . \]  

(30)

On the other hand if it is postulated that particle rest mass should include gravitational potential energy with

\[ m(r) = m_0 \exp \left[ \Phi(r) \right] \]

as in the Jordan frame of SCC, the comparison of \( m(r) \) and \( \nu(r) \), yields

\[ \nu(r) = \nu_0 . \]  

(31)

Thus the energy and hence frequency of a free photon is invariant in the Jordan frame, even when it transverses curved space-time. Contrary to GR, it might be thought self evident that as no work is done on or by a free-photon that obeys the equivalence principle, then its energy ought to be constant. As mentioned above, in the SCC Jordan frame gravitational red shift is interpreted not as a loss of potential energy by the photon but rather as a gain of potential energy, and therefore mass, by the observer’s apparatus.

The problem with the equivalence principle can now be restated; the rest mass of a raised body is invariant although work has been done lifting it, and the energy of a photon transmitted against a gravitational well deceases even though no work is done on or by it. In the Jordan frame of SCC this situation is reversed.

6 The SCC field equations

The functions \( T_{\phi, \mu \nu} \) and \( f_{\nu} (\phi) \) are calculated in the JF(E) to obtain the following set of field equations, [3]:

\[ \Box \phi = 4\pi T_M , \]  

(32)
(the scalar field equation),

\[ R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = \frac{8\pi}{\phi} T_{M\mu\nu} - \frac{3}{2\phi^2} \left( \nabla_\mu \phi \nabla_\nu \phi - \frac{1}{2} g_{\mu\nu} g^{\alpha\beta} \nabla_\alpha \phi \nabla_\beta \phi \right) \]

(33)

(34)

(35)

Also the Robertson parameters for SCC are given by the same formulas as in BD and in SCC are:

\[ \alpha_r = 1 \quad \beta_r = 1 \quad \gamma_r = \frac{1}{3} \]

(36)

Following BD, and GR, analysis of the ten PPN parameters reveals SCC to be a conservative theory with no preferred frame effect.

As we have seen the effect of allowing

\[ \nabla_\mu T^\mu_{M\nu} = \frac{1}{8\pi} \frac{\nabla_\nu \phi}{\phi} \Box \phi \]

is to produce an extra 'scalar field' force perturbing "free falling" slow moving particles from their geodesic paths. This force is found to be directly proportional to the purely gravitational force and, as the acceleration it produces on such bodies is independent of their mass, it behaves as Newtonian gravitation.
As a result the gravitational and scalar field accelerations would be confused in any experiment and convoluted together. Accordingly the Newtonian gravitational constant as measured in a Cavendish type experiment, $G_N$, is a compilation of $G_m$, which couples the curvature of space-time to mass, and the effect of the scalar field. A detailed calculation [3], yields

$$G_m = \frac{3}{2}G_N.$$  \hspace{1cm} (37)

Therefore the acceleration of a massive body caused by the curvature of space-time is $3/2$ the Newtonian gravitational acceleration actually experienced, however this is compensated by a force causing an anti-gravitational acceleration due to the scalar field of $1/2$ Newtonian gravity. Note that $G_N$ and $G_m$ refer to the total accelerations experienced in gravitational experiments by atomic particles and photons respectively. Consequently this theory makes definite and falsifiable predictions about observable measurements.

With these values $G_N$ is the proper value of $1/\phi$ at infinity, in ‘Cavendish’ type experiments this value of $G_N$ would be measured by atomic apparatus everywhere, as $G$ and $\phi$ only vary in the Jordan frame (i.e. in measurements using electromagnetic and gravitational methods alone). In SCC the Schwarzschild metric in the standard form is,

$$d\tau^2 = \left(1 - \frac{3G_NM}{rc^2} + \ldots\right) dt^2 - \frac{1}{c^2} \left(1 + \frac{G_NM}{rc^2} + \ldots\right) dr^2 - \left(\frac{r}{c}\right)^2 d\theta^2 - \left(\frac{r}{c}\right)^2 \sin^2\theta d\varphi^2. \hspace{1cm} (38)$$

The combined effect of space-time curvature and the scalar field force is given by the equations of motion of a freely falling particle as

$$\frac{d^2r}{dt^2} = -\left\{1 - \frac{G_NM}{rc^2} + \ldots\right\} \frac{G_NM}{r^2}. \hspace{1cm} (39)$$

The effect of this non-Newtonian perturbation will be shown later.

7 The Observational Tests of SCC

The SCC predictions will now be examined for the three original ‘classical’ tests of GR suggested by Einstein; the deflection of light by the sun, the gravitational red shift of light and the precession of the perihelia of the orbit of Mercury, together with three more recent tests, the time delay of radar echoes passing the sun, the precessions of a gyroscope in earth orbit and that ‘test-bed’ of GR, the binary pulsar PSR 1913 + 16. In several calculations of these tests, using the Robertson parameters, in which $G_m = \frac{3}{2}G_N$ and $\gamma_r = \frac{1}{3}$, the following factor, appears:

$$\frac{(1 + \gamma_r)}{2}G_m = G_N.$$  \hspace{1cm} (40)
Thus in these cases the effect of the scalar field perturbing the curvature of space-time from the GR curvature is exactly compensated by the effect of the scalar field acceleration on the measurement of $G$. This can be seen in the case of the deflection of light by a massive body where the deflection is given by

$$
\Delta \theta = \frac{4G_mM}{Rc^2} \left( \frac{1 + \gamma_r}{2} \right) = \frac{4G_NM}{Rc^2},
$$

(41)

which is the GR expression. SCC therefore agrees with GR and observation. This agreement also holds for measurements of the delay in the timing of radar echoes passing the sun and reflected off (say) Mercury, or a spacecraft, at superior conjunction. According to Misner, et al. [20] the deflection is given by

$$
\frac{d\Delta \tau}{dr} - \text{(Constant Newtonian part)} = -8 \left( \frac{1 + \gamma_r}{2} \right) \frac{G_mM}{bc^2} \frac{db}{dr} = -8 \frac{G_NM}{bc^2} \frac{db}{d\tau},
$$

(42)

where $b$ is the distance of the ray from the earth-sun axis. SCC thus predicts the GR value; this has been confirmed by observations to $\pm 1$ per cent. accuracy.

Although the scalar field similarly compensates for the effect of the curvature of space-time on the precession of a gyroscope in earth orbit in the frame-dragging precession it does not do so in the geodetic precession; so this latter measurement presents another test of the theory, which will be discussed below. If we now examine the precession of perihelia of an orbiting body, primarily the planet Mercury, we find that it does not fall into this type of relationship. In terms of the Robertson parameters the precession is given by the expression

$$
\Delta \theta = \frac{6\pi G_mM}{Lc^2} \frac{(2 - \beta_r + 2\gamma_r)}{3} \text{ radians/orbit.}
$$

(43)

Whereas in GR

$$
\Delta \theta = \frac{6\pi G_NM}{Lc^2}
$$

(44)

in agreement with observation to an accuracy $\pm 1$ per cent. Substituting the relevant values of $\gamma_r$ and $G_m$ for SCC in the above expression yields

$$
\Delta \theta = \frac{5\pi G_NM}{Lc^2}.
$$

(45)

However as the planet is a massive body it is subject to the scalar field acceleration, which modifies the Newtonian gravitation field with a dipole-like potential, so the total potential is

$$
\Phi = -\frac{G_NM}{r} + \frac{1}{2} \left( \frac{G_NM}{rc} \right)^2
$$

(46)

This is the well-known "semi-relativistic" potential obtained by enhancing the mass of an orbiting body with its potential energy and which produces a precession of

$$
\Delta \theta' = \frac{\pi G_mM}{Lc^2} \text{ radians/orbit.}
$$

(47)
Therefore, if one combines the precession calculated from the metric in SCC with the perturbation caused by the scalar field force, one obtains a prediction of precession for SCC that is exactly the same as GR,

\[ \Delta \theta = \frac{6\pi G_m M}{Lc^2} \text{ radians/orbit}. \] (48)

In SCC a neutron star, composed of relativistic matter with an equation of state of \( p = \frac{\rho c^2}{3} \), will be decoupled from the scalar field. Any predictions about the loss of orbital energy by the binary pulsar PSR1913+16 due to gravitational radiation would appear be the same as GR. However in the process of formation of such a collapsed star its gravitational field would appear to increase by a factor of 3/2 as its matter became degenerate and decoupled from the scalar field. This would assist the gravitational collapse of such an object so that the minimum mass limit, the Chandrasekhar limit, for a completely degenerate core is reduced from 1.4 to 0.93 solar mass, although this difference in mass would not be detectable except in the transitional case of a binary system caught in the act of becoming degenerate.

7.1 Experimental Tests of the Theory

It may be difficult for some to believe that a theory so different from GR could predict the same outcomes in all previous standard tests. It is therefore important to recall that in vacuo SCC test particles follow the trajectories of GR geodesics. Consistent with this is the fact that in SCC although the Robertson parameter \( \gamma = \frac{1}{3} \), whereas in GR \( \gamma = 1 \); this is compensated in most observations by an increase of \( G_m \) of 50 per cent. Consequently, we have been able to show that SCC is concordant with all those experiments that otherwise have been thought to verify GR.

However, may not the above identical predictions of GR and SCC in the One-Body Problem raise the suspicion that SCC is just GR rewritten in some obscure coordinate system? The existence of at least three types of experimental test that are suggested by SCC proves that this is not so. In this section we shall examine these definitive tests and in the next we shall consider the particular problem of the EEP.

The first type of test poses the following question: "Do photons and particles fall 'at the same rate'?" The prediction of the deflection of light by massive bodies is equal in both theories when observed at a distance; this is actually a scattering experiment. Nevertheless SCC predicts that a photon in free fall descends at 3/2 the acceleration of matter, i.e. in free fall a beam of light travelling a distance \( l \) is deflected downwards, relative to physical apparatus, by an amount

\[ \delta = \frac{1}{4} g_{Earth} \left( \frac{1}{c} \right)^2, \] (49)

where \( g_{Earth} \) is the terrestrial Newtonian gravitational acceleration. As a possible space experiment I suggest an annulus, two meters in diameter supporting,
for example, 1,000 carefully aligned small mirrors. A laser beam is then split, one half reflected, say 1,000 times, to be returned and recombined with the other half beam, reflected just once, to form an interferometer at source. If the experiment is in earth orbit and the annulus orientated on a fixed star, initially orthogonal to the orbital plane then the gravitational or acceleration stresses on the frame would vanish, whereas they would predominate on earth. In low Earth orbit SCC predicts a 2 Ångstrom \((2 \times 10^{-10} \text{m})\) interference pattern shift with a periodicity equal to the orbital period whereas GR predicts a null result.

This test may be carried out on Earth using the fact that the Earth is in free fall around the Sun and is accelerating radially towards it at about \(0.01 \text{m/sec}^2\). For example, the laser beams of the LIGO gravity wave telescope travel horizontally along two orthogonal 4km tunnels and are then reflected back to be re-combined at an interferometer at source. For the experiment one beam could be returned immediately by an additional mirror to give it a negligible path length and then compared with the other beam that had travelled 8 km. The theory predicts that the two beams would then be displaced relative to each other in a direction towards the Sun by an amount

\[
\delta = \frac{1}{4} g_{\text{Sun}} \left( \frac{l}{c} \right)^2 \approx 2 \times 10^{-12} \text{metres},
\]

where \(g_{\text{Sun}}\) is the Newtonian gravitational acceleration of the Earth towards the Sun.

Although the LIGO interferometers can measure a longitudinal displacement to an accuracy of the order \(10^{-18} \text{m}\), whether they could have already detected a diurnal beam displacement of \(2 \times 10^{-12} \text{m}\), normal to the line of sight, is an interesting question. Nevertheless the adaptation of this existing apparatus with a suitably constructed interferometer may well be the cheaper method of testing whether light does "fall" at the same rate as matter, or otherwise.

The second type of test poses the following question: "Is there a limit to the Casimir force that is dependent on space-time curvature?" This question arises from the real vacuum solutions of the scalar potential, [3], which yield small non-zero densities if the curvature is non-zero. The Jordan frame requires a definite, small, negative vacuum density of virtual photons whereas the Einstein frame requires a small positive density of 'upwards' accelerating virtual particles. The theory thereby naturally connects gravitational theory with quantum expectations of the vacuum. These virtual densities are coupled to curvature and approach zero simultaneously with it. Thus it seems that SCC predicts a limit to the Casimir force as a function of space-time curvature that may be detectable. A rough calculation, dependent on the sensitivity of the apparatus, indicates that such a detection may be made in the solar system somewhere between the orbits of Jupiter and Saturn.

The third type test is being performed at present; it is the Gravity Probe B measurement of geodetic precession of a gyroscope in polar orbit around the Earth. On the one hand, the 'frame dragging' prediction of that experiment is
given by the expression:

\[ g_{i0} = -4G_m \left( \frac{1 + \gamma_r}{2} \right) \int \frac{T^i_{\mu0} (x', t)}{|x - x'|} d^3x, \]  

(51)

so that the SCC values, \( \gamma_r = \frac{1}{3} \) and \( G_m = \frac{3}{2} G_N \), give the same result as the GR values \( G_m = G_N \) and \( \gamma_r = 1 \). On the other hand, the geodetic precession is given by the expression

\[ \frac{1}{2} (2\gamma_r + 1) \frac{G_m M_\oplus}{R^3} v_s \times X, \]  

(52)

where \( M_\oplus \) is the mass of the Earth; so that the SCC prediction is \( \frac{5}{6} \) of that of the GR prediction of 6.6144 arc sec/yr about a direction perpendicular to the plane of the orbit. In SCC there is a Thomas precession, which has to be subtracted from the geodetic precession, of

\[ \frac{1}{6} \frac{G_m M_\oplus}{R^3} v_s \times X, \]  

(53)

Therefore, the SCC theory prediction of a N-S precession of the GP-B gyroscope is \( \frac{2}{3} \) of that of the GR prediction, or just 4.4096 arcsec/yr. The SCC expectation of this experiment is that if the results are interpreted within a GR environment (setting \( G_m = G_N \)) then the values obtained for \( \gamma_r \) will be grossly inconsistent. If SCC is correct then such a GR analysis would yield \( \gamma_r = 1 \) from the frame dragging experiment but \( \gamma_r = 0.5 \) from geodetic precession. Such a gross inconsistency would be evidence falsifying the equivalence principle. This crucial measurement will be the first experiment that is able to distinguish between the two theories.

### 7.2 Potential Problems and Tests of the EEP

SCC contains a gross violation of the equivalence principle, which makes it problematical to believe that the theory could be concordant with the laboratory experimental tests of the EEP. There are two questions to answer. The first is, "If there are many different types of matter present, how does the scalar field \( \phi \) couple to the individual matter components? In particular, how is the lack of conservation of the total stress-energy \( T_{\mu\nu} \) shared among the different fields?"

The second question, the answer of which depends partly on the first and partly on first principles, is, "If it is really true that 'photons fall at a faster rate than particles by a factor of 3/2', then electromagnetic fields must couple very differently to the metric and/or \( \phi \) than other forms of matter. However, as a nontrivial portion of the mass-energy of atoms is electromagnetic in origin, and this fraction varies substantially from material to material, would not one expect different types of materials to fall at different rates?"

In answer to the first question we recall that our scalar and creation field equations are given by

\[ \Box \phi = 4\pi T_M \]
and

\[ \nabla_\mu T^\mu_{M\nu} = \frac{1}{2} \frac{\nabla_\nu \phi}{\phi} T_M \]

respectively, so the scalar field and the 'lack of conservation' couple to different matter components according to their trace \( T_M \).

The second question requires a little more thought. One of the basic principles of the theory is that of Mach. This is enshrined by the scalar field equation. As totally relativistic forms of energy, which have an equation of state \( p = \frac{1}{3} \rho c^2 \), are traceless they are decoupled from the scalar field. This is entirely consistent with Mach’s principle and Special Relativity; for as according to the latter the speed of light is invariant across all frames of reference then one cannot define an inertial frame of reference using the distribution of light and other forms of free relativistic energy within the universe. This is the macroscopic case.

However the microscopic case is more uncertain as it is encompasses the interface between gravitational and quantum physics. We note that the similar question of how the gravitational and scalar fields couple to matter on the atomic and nuclear scale has not yet been answered in the GR or BD theories either. What is clear is that, in order for SCC not to contradict the experimental results of the EEP, it has to be assumed that once electromagnetic energy is atomically bound and hence 'located' within an atom, so its mass equivalent must be accounted for with that atom as far as Mach’s principle is concerned. Such energy does therefore contribute to the overall trace of the matter it is bound to. The density and pressure values that enter into the set of field equations must therefore be the average macroscopic values of the continuum of matter. The question is whether or not this requirement is plausible.

Accordingly, how then do different materials accelerate within a gravitational field? Present day tests of the EEP have confirmed that different elements such as gold and aluminium fall at the same rate to within one part in \(10^{-14}\). Treating different elements as perfect fluids, the violation of the EEP is due to the pressure of stress energy compared with rest mass. The full equation of motion is given by [21]

\[
\frac{d^2 r}{dt^2} = - \frac{3}{2} \left[ 1 - \frac{(\rho c^2 - 3p)}{3\rho c^2} \right] \frac{G_N M_\oplus}{r^2} + \left[ 3 - 2 \left( \frac{\rho c^2 - 3p}{\rho c^2} \right) \left( \frac{G_N M_\oplus}{r c^2} \right) \frac{G_N M_\oplus}{r^2} \right] \left( \frac{G_N M_\oplus}{r c^2} \right) + O \left( \frac{G_N M_\oplus}{r c^2} \right)^2. \tag{54}\]

Deviations from the EEP are thus one part in \( \frac{3p}{\rho c^2} \) and as the second term is a factor \( 7 \times 10^{-10} \) smaller than the first, on the Earth’s surface, it can be ignored. The deviation for aluminium under atmospheric pressure is therefore one part in \( 6 \times 10^{-16} \). However experiments to such accuracy are actually carried out in a vacuum in which the only pressure is due to the internal stress set up by the weight of the object. The maximum internal pressure of a body of height \( h \) is \( \rho gh \), therefore the deviation from the EEP is one part in \( gh c^{-2} \), or about
$h \times 10^{-16}$ where $h$ is measured in metres. Consequently in a typical Eötvos-type experiment the violation of the EEP would be about one part in $10^{-17}$ or about three orders of magnitude smaller than the present day sensitivity of the experiment.

8 The Cosmological Solution

Using the cosmological principle the usual assumptions of homogeneity and isotropy can be made to obtain the cosmological solutions to the field equations, [3]. The privileged CoM frame in which physical units may be defined for any epoch is now the 'rest frame' for the universe as a whole in which the Cosmic Background Radiation is isotropic. Transformations between the Jordan, and Einstein, frames have to be made as appropriate.

The gravitational field equation is the same as the BD equation with $w = -\frac{3}{2}$; where a superimposed dot signifies the time derivative,

$$
\left(\frac{\dot{R}}{R}\right)^2 + \frac{k}{R^2} + \frac{8\pi \rho}{3\phi} \frac{\ddot{\phi}R}{\dot{\phi}R} - \frac{1}{4} \left(\frac{\dot{\phi}}{\phi}\right)^2,
$$

which is obtained from the time-time and space-space components. The second equation derived from the gravitational field equation also includes the scalar field equation,

$$
\frac{\ddot{R}}{R} + \left(\frac{\dot{R}}{R}\right)^2 + \frac{k}{R^2} = -\frac{1}{6} \left(\frac{\dot{\phi}}{\phi} + 3 \frac{\ddot{\phi}R}{\dot{\phi}R}\right) + \frac{1}{4} \left(\frac{\dot{\phi}}{\phi}\right)^2.
$$

The third equation is the same as the BD scalar field equation:

$$
\dddot{\phi} + 3 \frac{\dot{\phi}R}{R} = 4\pi (\rho - 3p).
$$

In GR and BD a fourth equation is obtained from the conservation requirement:

$$
\dot{\rho} = -3 \frac{\dot{R}}{R} (\rho + p),
$$

but here it is replaced by,

$$
\dot{\rho} = -3 \frac{\dot{R}}{R} (\rho + p) + \frac{1}{8\pi \phi} \left(\dot{\phi} + 3 \frac{\ddot{\phi}R}{R}\right),
$$

with an extra term representing cosmological 'self-creation'. It is a moot point whether the scalar field $\phi$ is generated by the distribution of mass and or whether mass is generated by the scalar field. A fifth equation is obtained from some equation of state, $p = \sigma \rho$, where, for example, $\sigma = +1/3$ in a radiation dominated, and $\sigma = 0$ in a dust filled, universe, but the SCC field equations demand
an exotic equation of state. There are therefore five independent equations to solve for six unknowns \( R(t), \phi(t), \rho(t), \) and \( \sigma, \) and a sixth relationship is provided by Stephan’s Law and the conservation of a free photon’s energy in the Jordan frame. The boundary conditions at \( t = t_0 \) (the present epoch), are known, \( R_0, \phi_0, \rho_0, \) and \( p_0. \) The cosmological equations can be reduced to a relationship between \( \rho(t), R(t), \) and \( \phi(t), \)

\[
\rho = \rho_0 \left( \frac{R}{R_0} \right)^{-3(1+\sigma)} \left( \frac{\phi}{\phi_0} \right)^{\frac{1}{2}(1-3\sigma)},
\]

which again is the equivalent GR expression with the addition of the last factor representing cosmological ’self-creation’.

For a photon gas \( \sigma = \pm \frac{1}{3} \) so the last expression reduces to its GR equivalent, \( \rho_{em} \propto R^{-4}, \) consistent with the PMI principle that there is no interaction between a photon and the scalar field. Furthermore, by Stephan’s law, \( \rho_{em} \propto T_{em}^4, \) where \( T_{em} \) is the Black Body temperature of the radiation, therefore the adiabatic GR relationship

\[
T_{em} \propto R^{-1}
\]

still holds. As the wavelength \( \lambda_{em}^{max} \) at maximum intensity of the Black Body radiation is given by

\[
\lambda_{em}^{max} \propto T_{em}^{-1},
\]

SCC retains the GR relationship \( \lambda_{em}^{max} \propto R. \) However the SCC contention is that gravitational, and hence cosmological, equations have to be solved in the Jordan frame in which \( \lambda \) is invariant, thus in this frame \( R \) must be invariant as well. In other words the universe is stationary because a co-expanding ”light-ruler” would be unable to detect an expanding universe! In the Jordan frame with

\[
R = R_0
\]

the cosmological equations reduce to

\[
(5 - 3\sigma) \frac{\dot{\phi}}{\phi} = 3 (1 - 3\sigma) \left( \frac{\dot{\phi}}{\phi} \right)^2,
\]

which has the two possible solutions; case 1, when \( \sigma \neq -\frac{1}{3} \) - then

\[
\phi = \phi_0 \left( \frac{t}{t_0} \right)^{\frac{(5-3\sigma)}{2(1+3\sigma)}},
\]

and case 2, when \( \sigma = -\frac{1}{3} \) then

\[
\phi = \phi_0 \exp \left[ H(t - t_0) \right],
\]

where \( H \) is some as yet undetermined constant of dimension \( [T]^{-1}. \)
Case 1 is that of a universe empty except for a false vacuum, in which the presence of any other energy or matter forces the solution to take on case 2 in which the cosmological density is given by

$$\frac{8\pi \rho}{\phi_0} = H^2 \exp [H (t - t_0)] \ .$$

(67)

Assuming baryon conservation in a stationary universe, the inertial mass of a fundamental particle, $m_i$, is given by

$$m_i = m_0 \exp [H (t - t_0)] \ .$$

(68)

Cosmological red shift is not interpreted as an effect caused by cosmological expansion, but rather as gain in the mass of the apparatus measuring it, as with gravitational red shift. Observations of the cosmological red shift identify $H$ as Hubble’s ‘constant’.

It is now necessary to transform from the Jordan frame used in the theory into the system of measurement used in the laboratory, that is the Einstein frame. The secular cosmological gain in inertial mass causes atoms and therefore rulers to ‘shrink’ and atomic clocks to ‘speed up’ when compared to their Jordan frame equivalents. Care has to be taken in interpreting cosmological measurements, as they are often observations of a mixture of Jordan and Einstein frame effects. In the Jordan frame distance and time are given by $r$, $R$ and $t$; in the Einstein frame they shall be expressed by italicised $r$, $R$ and $t$. In the Jordan frame if the origin of the time system is defined to be the present moment, $t_0 = 0$, then as $t \to -\infty$ the masses of fundamental particles tend towards zero, and hence the sizes of the particles will tend towards infinity; whereas in the Einstein frame at this ‘Big Bang’ epoch, the universe has zero volume although particles are of normal size. In either case the universe is equally crowded! Hence it is natural in the Einstein frame to define this epoch, marking the initial moment of the ‘Big Bang’ to be the origin, $t = 0$. The two time systems then relate together as follows:

$$t = H^{-1} \exp (Ht) \text{ and } t = H^{-1} \ln (Ht) \ .$$

(69)

In the Einstein frame, $R = R_0(t/t_0)$, and the universe thus appears to expand linearly from a ‘big bang’. Because the deceleration parameter $q = - \left( \dot{R}/H^2 R \right)$ equals zero in SCC as $\dot{R} = 0$, the horizon, smoothness and density problems of classical GR cosmology, which all arise from a positive non-zero $q$, do not feature in SCC. Therefore in this theory it is unnecessary to invoke Inflation theory and indeed, instead, SCC might be considered to be a form of ‘Continuous Inflation’.

The above equations give the cosmological density as

$$\rho_0 = \frac{H_0^2}{8\pi G_N} \ ,$$

(70)
where $G_N$ is the value of $\phi^{-1}$ in the present epoch, from which the total density parameter

$$\Omega = \frac{1}{3}.$$  \hspace{1cm} (71)

The cosmological equations require the cosmological pressure to be $p = -\frac{1}{3} \rho$. This exotic equation of state appears to have the form of a non-zero cosmological constant. However instead, in a similar fashion to the One Body case, there is a false vacuum component of the universe created by the scalar field. SCC therefore suggests that there is a 'remnant' vacuum energy made up of contributions of zero-point energy from every mode of every quantum field that would have a natural energy 'cut-off' $E_{\text{max}}$ determined and limited by the solution to the cosmological equations. This component of false vacuum is calculated to have a density of one-third the total density; hence the remaining cold matter (visible and dark) density parameter is determined by

$$\Omega_{fv} = \frac{1}{9} \text{ and therefore } \Omega_b = \frac{2}{9} = 0.22.$$  \hspace{1cm} (72)

The difference between $\Omega$ and $\Omega_b$ could be interpreted as the hot dark matter component of 'missing mass' or, with negative pressure, it might have been identified with 'dark energy' or 'quintessence' [22], [23], [24].

The curvature constant, $k$, is found to be positive, so the universe is finite and unbounded, with a 'radius of curvature'

$$R_0 = \frac{\sqrt{12}}{H_0} c.$$  \hspace{1cm} (73)

By definition the mass of a fundamental particle, $m$, is constant in the Einstein frame, however when compared with the energy of a free photon, the mass is given by,

$$m = m_0 \left( \frac{t}{t_0} \right) = m_0 \left( \frac{R}{R_0} \right),$$  \hspace{1cm} (74)

which is normally interpreted in this frame as the free photon suffering a red shift, $1 + z = R_0/R$. Similarly, using Einstein frame time, $\phi$ is given by

$$\phi = G_N^{-1} \left( \frac{t}{t_0} \right),$$  \hspace{1cm} (75)

but this variation is normally 'hidden' by the compensating change in atomic masses that causes GM to be constant.

Nevertheless this relationship might explain the Large Numbers Hypothesis (LNH) relationship $G \approx T^{-1}$ where $G$ and $T$ are the normal LNH dimensionless values of the gravitational constant and the age of the universe respectively.

The observation of any variation in $G$ will depend on the techniques used. If Hubble time is of the order $15 \times 10^9$ years then according to the theory:

$$\frac{\dot{G}(t)}{G(t)} \approx -6 \times 10^{-11} \text{ yr}^{-1}.$$  \hspace{1cm} (76)
This may have already been observed. Krasinsky’s et al. result from the analysis of the residuals of planetary longitudes [25] is:

\[ \frac{G(t)}{G(t)} \approx + (4 \pm 0.8) \times 10^{-11} \text{yr}^{-1} \]  

(77)

with a caveat that the sign might be reversed. However they also reported the contradictory null result of Hellings et al., [26], determined from accurate observations of the Viking Landers and the Mariner 9 spacecraft with the effect that a possible falsification of GR was not followed up. However SCC may explain the discrepancy between these two results. The residuals of planetary longitudes are ‘remote’, gravitational, observations that are to be interpreted in the Jordan frame, whereas the radar ranging of a spacecraft depended on an atomic clock. In which case the secular increase in atomic mass would affect clock rate and hence compensate for the variation in G to give a null result.

The gravitational field of a massive body remains invariant over cosmological time in the Einstein frame. This effect, which manifests itself as a ‘time slip’ between atomic and gravitational clocks, that is, between ‘atomic time’ and ‘ephemeris time’, also explains the anomalous sunward acceleration observed on the Pioneer spacecraft [4], [5], [27].

Summing up, in the JF(E), where energy is conserved but energy-momentum is not, photons are the means of measuring length, time and mass. Proper mass increases with gravitational potential energy and therefore cosmological red shift is caused by a secular, exponential, increase of particle masses and not cosmological expansion. The universe is stationary, in which atomic rulers ‘shrink’ exponentially, and eternal, in which atomic clocks ‘speed up’ exponentially.

### 8.1 An explanation for some anomalous observations

The consequence of this theory is the realisation that there are two distinct ways of interpreting observations of the universe. In a laboratory on Earth scientific observations that define units of length, time and mass/energy have to be referred to an atomic standard. However, astrophysical and cosmological observations only sample photons from the depths of the universe. How then does the measurement of the standard units made in a laboratory here and now on Earth relate to an event that occurred millennia ago in a distant part of the universe? In particular, the problem is rooted in the red shift of photons over and above that caused by the Doppler effect.

Because of the equivalence principle GR defines the proper rest mass of a particle to be invariant, therefore that theory requires the measures of standard units to be atomic ‘rigid’ rulers and atomic ‘regular’ clocks. However, the penalty for doing so is to violate the conservation of mass-energy as described in the Introduction above. On the other hand, if a gravitational theory were to locally conserve energy, as in the theory of SCC, which for consistency also subsumes Mach’s Principle, then atomic rest masses would vary with gravitational potential energy. If this indeed occurs then a choice may be made as
to the invariant standard by which units of length, time and mass/energy are measured. This choice of the standard for comparison is between a 'standard' atom, taken from a laboratory, or a 'standard' photon, sampled from the CMB. Observations of the cosmos would then reveal one of two possible universes: either a stationary universe that is eternal with no origin in time, the JF(E) interpretation, or a strictly linearly expanding or 'freely floating' universe that has had an 'origin' in a 'Big Bang' at one 'Hubble Time' in the past, the EF interpretation. Either model would be a valid interpretation of the data, the JF(E) would be the appropriate frame to observe gravitational or bits and the curvature of space-time, and the EF would be the appropriate frame to observe atomic processes such as primordial nucleo-synthesis.

It is remarkable that both these models, the stationary universe and the freely coasting universe, have already been independently investigated and both have been found to be surprisingly concordant with accepted cosmological constraints, including the Big Bang nucleo-synthesis abundances, distant Type Ia supernovae observations and the WMAP CMB anisotropy data.

Ostermann, [5], investigated the stationary universe heuristically, he included an exponential cosmological time slip in his theory and found it was able to explain the Pioneer anomaly and fit the standard concordance model perfectly [28].

The strictly linearly expanding or freely coasting model has been investigated by Kolb, [29], Dev, Safonova, Jain and Lohiya, [30], Gehaut, Mukherjee, Mahajan and Lohiya, [31], and Gehaut, Kumar, Geetanjali and Lohiya, [32]. Their motivation in exploring such a cosmology was the recognition that such a model would not have suffered from the original density, smoothness and horizon problems of the standard GR theory. The latter paper reviews their results and finds the freely coasting universe fits the Type 1a supernovae data. Moreover, the recombination history gives the location of the primary acoustic peaks of the WMAP data in the same range of angles as that given in standard cosmology. A further remarkable result is their analysis of nucleo-synthesis in the Big Bang. They calculate that a baryon entropy ratio of $\eta = 5 \times 10^{-9}$ yields 23.9 per cent Helium and $10^8$ times the metallicity of the standard scenario, which is still of the same order of magnitude as seen in the lowest metallicity objects. Therefore, one prediction of the theory is that a significant proportion of intergalactic medium metallicity, observed from the Lyman a forest of distant quasar spectra, should be primordial.

A further consequence is, interestingly, that the production of this amount of helium requires a baryon density parameter of about 0.2. As the total non-false vacuum energy density is required by SCC to be only 0.22, there is no need for unknown dark matter. In SCC, this component of the cosmic density parameter is in the form of intergalactic cold baryonic matter.

Furthermore, the cosmological solution requires the universe to have an overall density parameter of only one third, yet be closed and conformally spatially flat. Hence, the theory does not require dark energy, or a significant amount of dark matter, to account for the present cosmological constraints.

In SCC the vacuum energy density is negative and stably determined by the
field equations, with no cosmological constant thus fulfilling the requirements of present superstring models. The high baryonic matter density also relieves the problem over the galaxy mass profiles that require low energy density to fit the observed cusp.

Another observable effect arises in the JF(E) as a result of the variation in \( m(t) \). If angular momentum is conserved then \( mr^2 \omega \) is constant. An atomic radius is inversely proportional to its mass, so if the mass increases secularly, the radius will shrink.

If \( m(t) = m_0 e^{H_0 t} \), then \( r(t) = r_0 e^{H_0 t} \)  
(78)

\[
\frac{d}{dt} (mr^2 \omega) = 0
\]
(79)

Then \( \dot{\omega} = - \left( \frac{\dot{m}}{m} + 2 \frac{\dot{r}}{r} \right) = +H_0 \)
(80)

and solid bodies such as the Earth should spin up when measured by JF(E), (ephemeris) time. It has indeed been reported that this is observed. As mentioned above, the review by Leslie Morrison and Richard Stephenson, [6], [7], studying the analysis of the length of the day from ancient eclipse records reported that in addition to the tidal contribution there is a long-term component acting to decrease the length of the day which equals

\[
\triangle T/\text{day/ct} = -6 \times 10^{-4} \text{ sec/day/ct}.
\]
(81)

This value, equivalent to \( H = 67 \text{ km/sec}^{-1}/\text{Mpc} \), is remarkably close to the best estimates of \( H_0 \). The lunar orbit, being a geodesic through space-time, makes a JF(E) clock, it "tells ephemeris time", so this observation is exactly that predicted by SCC. However at least part of this spin up is probably caused by a decrease of the Earth’s moment of inertia.

9 A novel representation of space-time geometry

In the stationary model of the SCC JF(E), a space-like slice of space-time produces a hyper-sphere independent of the slice chosen, whereas a time-like slice produces a cylinder. It is Einstein’s stationary cylindrical model. In the EF, on the other hand, consecutive space-like slices produce a series of hyper-spheres whose radii are proportional to the age of the space slice chosen, whereas a time-like slice produces a conical model. The series of hyper-spheres that steadily increase may be re-arranged into a series of concentric hyper-spheres. The model is now that of a radial time universe. Treating time as a radial coordinate has several attractions. As a radial coordinate it has an origin but no negative values, time just did not exist before \( t = 0 \), the Big Bang. A child-like question may be, "What is the universe expanding into?" The answer may be given,
"The future". In such a model the expansion of the universe and the passing of time may be seen as two different experiences of the same phenomenon, yet what that phenomenon may be still remains a mystery.

10 Conclusions

Whereas GR cosmology can be considered as a model with two free parameters, \( \Omega \) and \( H \), this theory, SCC, has only one, \( H \), and its predictions are highly determined. Nevertheless in local experiments and in the basic cosmological parameters the theory does seem to yield reasonable predictions consistent with experiment. The theory explains the present quandary about the observed distant supernovae observations and yields predicted density parameters consistent with observation, which otherwise might be interpreted as the effects of a cosmological constant and/or quintessence. Furthermore, as a new theory of gravitation, SCC is readily open to falsification in the definitive experiments described earlier. The theory might be described as 'fully Machian' as

\[
\Omega_b = \frac{2}{9} \text{ yields } G_N = \frac{H_0^2}{12\pi\rho_b},
\]

(82)

and therefore the gravitational constant is fully determined by a knowledge of the large scale structure of the universe. It remains to be seen whether nucleosynthesis and gravitational instability analysis in the SCC universe confirm the reasonable values for primordial element relative abundance and yields a plausible model for observed matter distribution.

Two of the attractive features of this theory are those of the self-creating nature of the universe ex nihilo, and the transposition of the initial moment of EF time, \( t = 0 \), back into the infinite past of JF(E) time, \( t \rightarrow -\infty \). Inertial rest mass is seen as a measure of total potential energy, that is the energy required to 'lift' a particle out of the 'Big Bang' to the present day. Inertial mass is created out of the zero point energy field by the self-contained gravitational and scalar fields within the universe, hence the suggested title of the theory. Finally there is a choice in the way time may be measured; depending on the clock used to measure it, the universe is understood either to have had a 'beginning', or to be eternal. The latter case thereby avoids philosophical problems associated with an origin.

11 References

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