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Modeling Repulsive Gravity with Creation

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Abstract. There is a growing interest among cosmologists for theories with negative energy scalar fields and creation, in order to model a repulsive gravity. The classical steady state cosmology proposed by Bondi, Gold & Hoyle in 1948, was the first such theory which used a negative kinetic energy creation field to invoke creation of matter. We emphasize that creation plays a very crucial role in cosmology and provides a natural explanation to the various explosive phenomena occurring in local ($z < 0.1$) and extra galactic universe. We exemplify this point of view by considering the resurrected version of this theory – the quasi-steady state theory, which tries to relate creation events directly to the large scale dynamics of the universe and supplies more natural explanations of the observed phenomena.

Although the theory predicts a decelerating universe at the present era, it explains successfully the recent SNe Ia observations (which require an accelerating universe in the standard cosmology), as we show in this paper by performing a Bayesian analysis of the data.

Key words. Cosmology: theory, observation, creation—negative energy fields—SNe Ia.

1. Introduction

Remarkable progress has been made in various types of astrophysical and cosmological observations in recent years. Among these, the accurate measurements of the anisotropies in the CMB made by the WMAP experiment appear to offer the most promising determination of the cosmological parameters. The results of the WMAP experiment are however often quoted as providing a direct evidence for an accelerating universe, which however is not correct. The cosmological constraints as established by the WMAP team (Spergel *et al.* 2003) entirely rely on the power law spectrum assumption and could be erroneous (Kinney 2001; Hannestad 2001). Taken on their face value, the WMAP observations are fully consistent with the decelerating models like the CDM Einstein-de Sitter model (Vishwakarma 2003; Blanchard 2005).

The possibility of an accelerating universe in fact emerges from the measurements of distant SNe Ia, which look fainter than they are expected in the standard decelerating models. This observed faintness is generally explained by invoking some hypothetical source with negative pressure generally known as *'dark energy'*. This happens because the metric distance of an object, out to any redshift, can be increased by incorporating a *'fluid'* with negative pressure in Einstein's equations and hence the object looks fainter. The simplest and the most favoured candidate of dark energy is a positive cosmological constant Λ, which is however plagued with the horrible fine tuning problems – an issue amply discussed in the literature. This has led a number of cosmologists to resort to scalar field models called quintessence whose function is to cause the scale factor to accelerate at late times by violating the strong energy condition. While the scalar field models enjoy considerable popularity, they have not helped us to understand the nature of dark energy at a deeper level. By and large, the scalar field potentials used in the literature have no natural field theoretical justification and have to be interpreted as a low energy effective potential in an *ad hoc* manner. Moreover they also require fine tuning of the parameters in order to be viable (to find several other shortcomings, see for example, Padmanabhan 2005).

As desperate times call for desperate measures, the cosmologists, in order to model the dark energy, have now turned to *'phantom'* or *'ghost'* scalar field models with negative kinetic energy (Caldwell 2002; Carroll *et al.* 2003; Gibbons 2003; Singh *et al.* 2003; Sami & Toporensky 2004). The classical steady state cosmology proposed by Bondi & Gold (1948) and Hoyle (1948) was the first such theory which used a negative kinetic energy creation field to invoke creation of matter. It is interesting to note that, distinct from all the existing big bang models at that time, this model predicted an accelerating universe. However, it is unfortunate that the theory was not given any credit (which it deserved, despite the difficulties associated with it) when the SNe Ia observations started claiming an accelerating universe in 1998.

Once cosmologists have lost their inhibitions about negative energy fields, the time is ripe for considering the idea that the creation of matter plays an important role in cosmology. We exemplify this point of view by considering the resurrected version of the classical steady state theory, namely the quasi-steady state cosmology (QSSC) which has not been given proper attention as it deserves. This theory was proposed by Hoyle, Burbidge & Narlikar in 1993 (1993; 1995), wherein the introduction of negative kinetic energy scalar field is not *ad hoc* but is required to ensure that matter creation does not violate the law of conservation of matter and energy. However, first we emphasize that the idea of creation of matter is already present in general relativity, though hidden behind some simplifying assumptions.

With a suitable Lagrangian for the source terms, the Einstein field equations can be written as

$$R_{ik} - \frac{1}{2} g_{ik} R = -8\pi G [T_{ik}^{(\text{matter})} + T_{ik}^{(\Lambda)} + T_{ik}^{(\phi)} + \cdots], \tag{1}$$

where we have considered the speed of light $c = 1$. The only constraint on the source terms, which is imposed by this equation, is the conservation of the right-hand side through the Bianchi identities: $[R_{ij} - \frac{1}{2} R g_{ij}]^{;j} = 0 = [T_{ij}^{(\text{matter})} + T_{ij}^{(\Lambda)} + T_{ij}^{(\phi)} + \cdots]^{;j}$, implying that only the sum of all the energy-momentum tensors is conserved, individually they are not. If we take them conserved separately, as is in practice among the cosmologists, it can be done only through the additional assumption of no interaction (minimal coupling) between different source fields, which though seems *ad hoc* and nothing more than a simplifying assumption. On the contrary, interaction is more natural and is a fundamental principle. Of course some ideal cases are consistent with the idea of minimal coupling, for example, $T_{ik}^{(\text{matter})}$ with a constant Λ. However, imposing this assumption on non-trivial cases would result in losing some important information. For example, taken on face value, a time-dependent Λ, with matter, implies matter creation and results in a Machian model (Vishwakarma 2002a). However, if one makes an additional assumption of no interaction between $T_{ik}^{(\text{matter})}$ and $\Lambda(t)$, these features are lost and $\Lambda(t)$ reduces to a constant. It is well known that even if one considers the Robertson–Walker spacetime (to avoid non-Machian Godel's solution of Einstein field equations), there still exists a non-Machian solution of Einstein field equations – the de Sitter solution. Creation has many more attractive features. It has been shown how the scalar creation field helps in resolving the problems of singularity, flatness and horizon in cosmology (Narlikar & Padmanabhan 1985). Such a negative energy creation field is responsible for a non-singular bounce from a high non-singular density state, as has been shown by Hoyle & Narlikar (1964). This idea has been recently used by Steinhardt and Turok in their oscillatory model (Steinhardt & Turok 2002). The quasi-steady state cosmology (QSSC) is also a Machian theory which is derived from an action principle based on Mach's Principle, and assumes that the inertia of matter owes its origin to other matter in the Universe. The stress-energy tensor for creation (corresponding to $T_{ik}^{(\phi)}$ in equation (1)) is given by

$$T_{ik}^{\text{creation}} = -f\left(C_i C_k + \frac{1}{4} C^l C_l \, g_{ik}\right), \tag{2}$$

where f is a positive coupling constant and the gradient $C_i \equiv \partial\phi/\partial x^i$ is the contribution from a trace-free zero rest mass scalar field ϕ of *negative* energy and stresses. The Λ in this theory (corresponding to a $T_{ik}^{(\Lambda)} \equiv -\Lambda g_{ik}/8\pi G$ of (1)) appears as a constant of nature with its value $\approx -2 \times 10^{-56}\ \text{cm}^{-2}$, which falls within the normally expected region of the magnitude of the cosmological constant. However, note that its sign is negative, which is a consequence of the Machian origin of the cosmological constant. The theory does not face the cosmological constant problem mentioned earlier. In fact, the Λ in the QSSC does not represent the energy density of the quantum fields, as this model does not experience the energy scales of quantum gravity except within the local centres of creation. The theory offers a purely stellar-based interpretation of all observed nuclei including the light ones (Burbidge *et al.* 1957; Burbidge & Hoyle 1998). In the following, we demonstrate in brief the main features of this cosmology and how it confronts the various observations (for more details, one can consult Sachs *et al.* 1996; Hoyle *et al.* 2000).

The QSSC represents a cyclic universe with its Robertson–Walker scale factor given by

$$S(t) = e^{t/P}\left[1 + \eta \cos\left(\frac{2\pi\tau}{Q}\right)\right], \tag{3}$$

where the timescales $P \approx 10^3$ Gyr $\gg Q \approx 40$–50 Gyr are considerably greater than the Hubble time scale of 10–15 Gyr of the standard cosmology. The function $\tau(t)$ is very nearly like the cosmic time t, with significantly different behaviour for short duration near the minima of the function $S(t)$. The parameter η has modulus less than unity, thus preventing the scale factor from reaching zero. Typically, $\eta \sim 0.8 - 0.9$. Hence there is no space-time singularity, or a violation of the law of conservation of matter and energy, as happens at the big bang epoch in the standard cosmology. The model has cycles of expansion and contraction (regulated respectively by the creation field and the negative Λ) of comparatively shorter period (Q) superposed on a long term (P) steady state-like expansion. Creation of matter, which occurs through explosive processes, is also periodic, being confined to pockets of strong gravitational fields around compact massive objects and the nuclei of existing galaxies. Such processes take place whenever the energy of the creation field quantum rises above a threshold energy, which is equal to the restmass energy of the created Planck particle.

The model provides a natural explanation to the various explosive phenomena occurring in local ($z < 0.1$) and extra galactic universe. By the early 1960s it had become clear that very large energy outbursts are taking place in the nuclei of galaxies. In the decades since then it has been found that many active nuclei are giving rise to X-rays, and relativistic jets, detected in the most detail as high frequency radio waves. A very large fraction of all of the energy which is detected in the compact sources is non-thermal in origin, and is likely to be incoherent synchrotron radiation or Compton radiation. In addition to this, we see several other explosive phenomena in the Universe, such as jets from radio sources, gamma-ray bursts, X-ray bursters, QSOs, etc. Generally it is assumed that a black hole plays the lead role in such an event by somehow converting a fraction of its huge gravitational energy into large kinetic energy of the 'burst' kind. In actuality however, we do not see infalling matter that is the signature of a black hole. Rather we see outgoing matter and radiation, which agree very well with the idea of creation events formulated in the framework of the QSSC.

There are several free parameters in the model which are estimated from the observations and provide a decelerating universe at the present cycle of expansion. It is then interesting to see how the model explains the SNe Ia and other observations! This is shown in the following section.

2. The high redshift supernovae Ia

It is generally accepted that metallic vapours are ejected from the SNe explosions which are subsequently pushed out of the galaxy through pressure of shock waves (Hoyle & Wickramasinghe 1988). Experiments have shown that metallic vapours on cooling, condense into elongated whiskers of $\approx 0.5 - 1$ mm length and $\approx 10^{-6}$ cm cross-sectional radius (Donn & Sears 1963; Nabarro & Jackson 1958). It can be shown that the extinction from the whisker dust adds an extra magnitude $\delta m(z)$ to the apparent magnitude $m(z)$ (arising from the cosmological evolution) of the SN light emitted at the epoch of redshift z, which is given by

$$\delta m(z) = 1.0857 \times \kappa \rho_{g0} \int_0^z (1+z')^2 \frac{dz'}{H(z')}, \tag{4}$$

where κ is the mass absorption coefficient and ρ_{g0} is the whisker grain density at the present epoch. The net apparent magnitude is then given by

$$m^{net}(z) = m(z) + \delta m(z). \tag{5}$$

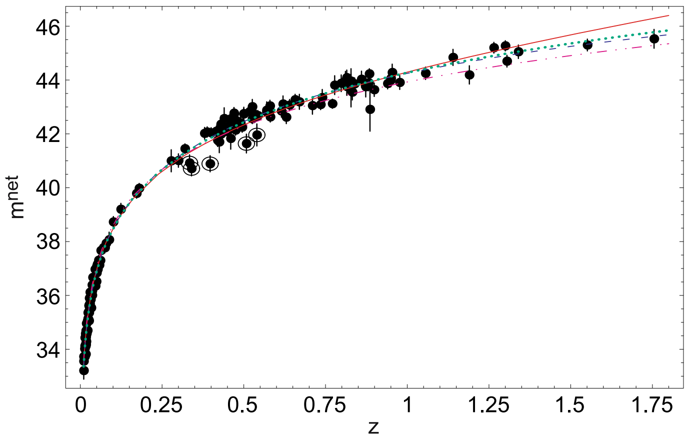

Figure 1. Some best-fitting models are compared with the 'gold sample' of SNe Ia data with 157 points as considered by Riess *et al.* (2004). The solid curve corresponds to the QSSC model with the whisker dust, the dotted curve corresponds to the flat ΛCDM model, the dashed curve corresponds to the spherical ΛCDM model, and the dashed-dotted curve corresponds to the Einstein-de Sitter model. The models differ significantly for $z > 1.2$. The encircled points seem to be general outliers which are missed by all the models.

By taking account of this effect, it has been shown that this kind of dust extinguishes radiation travelling over long distances and decelerating models without any dark energy (for example, the Einstein-de Sitter model) can also explain high redshift SNe Ia observations successfully (Vishwakarma 2002b, 2003, 2005). QSSC in fact resorts to this dust to explain not only the SNe Ia observations but also CMB, as we shall see in the following. It has been shown (Narlikar *et al.* 2002; Vishwakarma & Narlikar 2005) that by taking account of this effect, QSSC explains successfully the SNe Ia data from Perlmutter *et al.* (1999) and also shows an acceptable fit to the 'gold sample' of 157 SNe Ia recently published by Riess *et al.* (2004) which, in addition to having previously observed SNe, also includes some newly discovered highest-redshift SNe Ia by the Hubble Space Telescope. Though this sample is believed to have a 'high-confidence' quality of the spectroscopic and photometric record for individual supernovae, we note that there are some SNe (1997as, 1997bj, 2000eg, 2001iw, 2001iv) in this sample which do not seem to be consistent with any of the models generally considered in the fitting and appear as general outliers (see the encircled SNe in Figs. 1 and 2). By excluding these points, the fit to different models improves considerably. For example, the χ^2 value per degree of freedom (dof) for the best-fitting QSSC model reduces to 1.18 from the earlier $\chi^2/\text{dof} = 1.30$ obtained from the full sample of 157 points (Vishwakarma & Narlikar 2005). The fit to the standard (flat ΛCDM) cosmology improves tremendously from $\chi^2/\text{dof} = 1.14$ (from 157 points) to $\chi^2/\text{dof} = 0.99$ (from 152 points). The details of the fit (in the case of the frequentist approach) can be found in Vishwakarma & Narlikar (2005).

Though there is no clearly defined value of χ^2/dof for an acceptable fit, a *'rule of thumb'* for a *moderately* good fit is that χ^2 should be roughly equal to the number of dof. A more quantitative measure for the *goodness-of-fit* is given by the χ^2-*probability*. If the fitted model provides a typical value of χ^2 as x at n dof, this

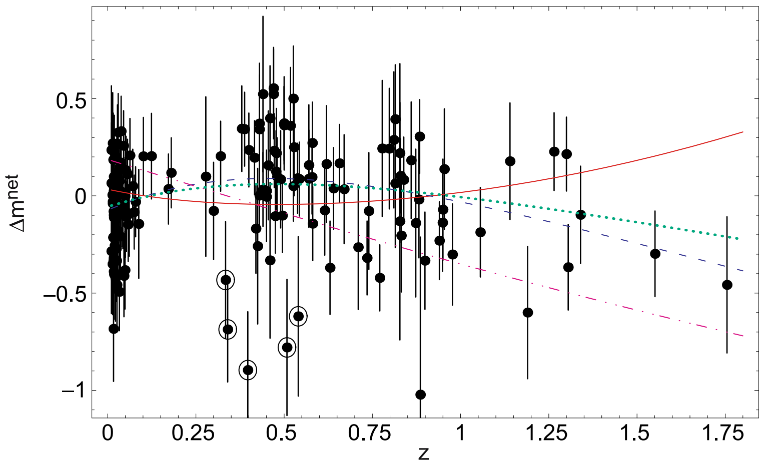

Figure 2. Modified Hubble diagram of the 'gold sample' of SNe Ia minus a fiducial model ($\Omega_{m0} = 0$, $\Omega_{\Lambda 0} = 0$). The relative magnitude ($\Delta m^{\rm net} \equiv m^{\rm net} - m_{\rm fiducial}$) is plotted for some best-fitting models, by using the original error bars. The solid curve corresponds to the QSSC model with the whisker dust, the dotted curve corresponds to the flat ΛCDM model, the dashed curve corresponds to the spherical ΛCDM model, and the dashed-dotted curve corresponds to the Einstein-de Sitter model. The encircled points seem to be general outliers which are missed by all the models.

probability is given by

$$Q(x, n) = \frac{1}{\Gamma(n/2)} \int_{x/2}^{\infty} e^{-u} u^{n/2-1} \mathrm{d}u. \tag{6}$$

Roughly speaking, it measures the probability that *the model does describe the data and any discrepancies are mere fluctuations which could have arisen by chance*. To be more precise, $Q(x, n)$ gives the probability that a model which does fit the data at n dof, would give a value of χ^2 as large or larger than x. If Q is very small, the apparent discrepancies are unlikely to be chance fluctuations and the model is ruled out. It may however, be noted that the χ^2-probability strictly holds only when the models are linear in their parameters and the measurement errors are normally distributed. It is though common, and usually not too wrong, to assume that the χ^2-distribution holds even for models which are not strictly linear in their parameters, and for this reason, the models with a probability as low as $Q > 0.001$ are usually deemed acceptable (Press *et al.* 1986). Models with vastly smaller values of Q, say, 10^{-18} are rejected. The probability Q for the best-fitting QSSC to the full sample is obtained as 0.007, which is though very small, but acceptable. By excluding the above-mentioned 5 outliers, Q improves to 0.062. The corresponding probabilities in the case of the standard ΛCDM cosmology are obtained as 0.109 and 0.534.

We note that the fit to the QSSC is considerably worse than those in the standard ΛCDM cosmology. However, one cannot compare the relative merits of the models on the basis of the χ^2-probability (frequentist approach), which uses the best-fitting parameter values and hence judges only the maximum likely performance of the models. The more appropriate theory for such comparisons is the Bayesian theory which does not hinge upon the best-fitting parameter values and evaluates the overall performance of the models by using average likelihoods (rather than the maximum likelihoods), given by the *Bayes factor* B. The theory employs the premise that if we assume an equal prior probability for competing models, the probability for a given model is proportional to the marginalised likelihood called *evidence*. We have described this theory, in brief, in the Appendix (for more details, see Drell *et al.* 2000; John & Narlikar 2002).

In order to calculate the Bayes factor B for the two models QSSC and the standard ΛCDM, first we have to fix the prior probabilities for the free parameters. While the flat QSSC has four free parameters $\kappa\rho_{g0}H_0^{-1}$, $\Omega_{\Lambda 0}$, $z_{\rm max}$ and $\mathcal{M}$ (see the Appendix of Vishwakarma & Narlikar (2005), the standard ΛCDM has only two free parameters Ω_{m0} and $\mathcal{M}$. We would like to mention that the whisker dust was already introduced in the QSSC in order to explain the CMB which put a constraint on the density of the dust $\rho_{g0} \approx 10^{-34}$ g cm^{-3} (Narlikar *et al.* 2003). This value, taken together with the observational constraints on κ (Wickramasinghe & Wallis 1996) and H_0 (Freedman & Turner 2003) from other observations, supplies a value of the parameter $\kappa\rho_{g0}H_0^{-1}$ close to the best-fitting value estimated from the SNe Ia observations. Hence we assign a prior on the parameter $\kappa\rho_{g0}H_0^{-1}$ that it lies in the range $\kappa\rho_{g0}H_0^{-1} \in [3.5, 6]$. We also note that $\Omega_{\Lambda 0}$ in the QSSC does not receive any significant contribution from $\Omega_{\Lambda 0} < -0.3$. Taking account of this and the theoretical constraint that Λ in the QSSC is negative, we assign a prior on the parameter $\Omega_{\Lambda 0} \in [-0.3, 0]$. To the rest two parameters in the QSSC, about which we do not have prior information, we assign liberal priors: $z_{\rm max} \in [5, 10]$ (to be consistent with the highest redshift ≈ 7 observed so far) and $\mathcal{M} \in [41, 45]$ (which is the common parameter). For the parameter Ω_{m0} in the flat ΛCDM model, we assume that $\Omega_{m0} \in [0, 1]$ (which is equivalent to assigning $\Omega_{\Lambda 0} \in [0, 1]$). It may be noted that the $\Omega_{\Lambda 0}$ in the two models are altogether different quantities (though they have been denoted by the same symbol in order to match the general convention) and there is no reason to assign the same probability for them in the two different models.

When calculated for the full 'gold sample' of 157 points, these prior probabilities give a Bayes factor favouring the standard ΛCDM over the QSSC as $B = 2.77$, which though indicates an evidence against the QSSC, however, the evidence is not definite and is not worth more than a bare mention (for the interpretation of B, see the Appendix). Our assigning $\Omega_{\Lambda 0} \in [-0.3, 0]$ in the QSSC can raise eyebrows, as this probability is very conservative compared to the one in the ΛCDM. However, assigning this probability is due to the reason that the likelihood for Λ in the QSSC does not receive any significant contribution from $\Omega_{\Lambda 0} < -0.3$, as mentioned earlier. For example, increasing the domain of Λ in its prior to $\Omega_{\Lambda 0} \in [-1, 0]$ in the QSSC, results in lowering the likelihood of the model, as expected. This gives the Bayes factor $B = 9.30$, which indicates that the evidence against the QSSC is definite, though not strong.

One should also note that a proper assessment of the probability for a model is given by $p = 1/(1+B)$. Thus for the above-mentioned two choices of the prior probabilities, the corresponding probabilities for the QSSC are 0.27 and 0.10, which are reasonably good probabilities.

It is interesting to note that the whisker dust, which is a vital ingredient of the QSSC, does not make any significant improvement in the fit to the ΛCDM cosmology. It may be argued that this kind of dust can create too much optical depth for the high redshift objects and they need to be excessively bright in order to be seen. However, from our calculations, we find that the objects over the present cycle right up to the maximum redshift will be fainter, at the most, by $\sim$ 6 magnitudes only and it is possible to see even sources from many previous cycles, though they will be very faint.

In Fig. 1, we have compared some best-fitting models with the actual data points. In order to have a better visual comparison of these models, we magnify their differences by plotting the relative magnitude with respect to a fiducial model $\Omega_{m0} = \Omega_{\Lambda 0} = 0$, without any whiskers (which has a reasonably good fit: $\chi^2/\text{dof} = 1.2$). This has been shown in the 'modified' Hubble diagram in Fig. 2. In the following sections we describe in brief, the other important features of the QSSC.

3. The CMB

As far as the origin and nature of the CMB is concerned, the QSSC uses a fact that is always ignored by standard cosmologists. If we suppose that most of the ^{4}He found in our own and external galaxies (about 24% of the hydrogen by mass) was synthesized by hydrogen burning in stars, the energy released amounts to about 4.37×10^{-13} erg cm^{-3}. This is almost exactly equal to the energy density of the microwave background radiation with $T = 2.74$ K! In the standard cosmology, this has to be dismissed as a coincidence. Thus according to the QSSC, the CMB is the relic starlight left by the stars of the previous cycles which has been thermalized by the metallic whisker dust emitted by the supernovae. As a typical cycle proceeds from the maximum of scale factor towards the next minimum, the wavelengths of the starlight from the previous cycle are shortened since the universe contracts by a considerable factor. It has been shown (Narlikar *et al.* 1997) that at wavelengths 100 m–20 cm, sufficient optical depth exists for this radiation to thermalize in about twenty cycles. The production of microwaves in this fashion goes on in each cycle, and the process of frequent absorption and re-radiation by whiskers will eventually generate a uniform background, *except for the contribution from the latest generation of clusters*. These will stand out as inhomogeneities on the overall uniform background arising from certain intrinsic inhomogeneities of the process as well as from the cosmological model. A quantitative analysis shows that this process requires an intergalactic dust of density of $\approx 10^{-34}$ g cm^{-3}, which is very close to the best-fitting value estimated from the SNe Ia observations. The theory also explains the peaks at $l \sim 200$ and $l \sim 600$ which are related, in this cosmology, to the clusters and groups of clusters (Narlikar *et al.* 2003). Also, we have taken stock of the WMAP observations in (Narlikar *et al.* 2007).

Though these studies do not give predictions as sharp as those given by the standard Big Bang cosmology, however, one should note the attitudinal difference between this approach and the standard one. In the Big Bang cosmology, the inferences are related to the postulated initial conditions prevailing well beyond the range of direct observations (at redshifts 1100). Whereas the QSSC interpretation links the inhomogeneities of the radiation field to those of the matter field, on which we do not have very accurate data at present, but which may be observable one day.

It may also be worthwhile to mention that there are claims that like the dipole, the quadrupole and the octopole harmonics of the CMB spectrum also have their origin in the solar system (Starkman *et al.* 2004). If this is correct, then subtracting this foreground contribution from the rest of the signal (in order to have the temperature fluctuations only at the time of the Big Bang) would place the inflationary model in serious trouble.

4. The non-baryonic dark matter

Unlike the standard big bang cosmology, the QSSC allows the dark matter to be baryonic. It may be recalled that the standard cosmology predicts the existence of non-baryonic, though as yet undetected, particles to solve the problems of structure formation and of the missing mass in bound gravitational systems such as galaxies and clusters of galaxies. The most favoured candidate of non-baryonic dark matter postulated by many astrophysicists, cosmologists and particle physicists is a massive but very weakly interacting particle called WIMP (Weakly Interacting Massive Particle), a hypothetical elementary particle that was produced moments after the Big Bang. Currently there are a number of WIMP detection experiments underway. Among these, the DAMA experiment (Bernabei *et al.* 2003), which measures the annual modulation in WIMP interactions with the sodium-iodide detectors caused by the earth's rotation around the Sun, is the only one to have claimed a positive signal. However, the results of this experiment are controversial as other more sensitive searches have not detected nuclear recoils due to WIMP interactions (Akerib *et al.* 2004; Angloher *et al.* 2005) and concluded that almost all the events measured by DAMA were from neutrons, and should not be attributed to scattering events from dark-matter WIMPs. It is therefore fair to say that this scheme has still to demonstrate its viability.

However, in the framework of the QSSC, the dark matter need not be necessarily non-baryonic. It can be in the form of baryonic matter being the relic of very old stars of the previous cycles. A typical QSSC cycle has a lifetime long enough for most stars of masses exceeding $\sim 0.5\text{–}0.7\,\mathrm{M}_\odot$ to have burnt out. Thus stars from previous cycles will be mostly extinct as radiators of energy. Their masses will continue however, to exert a gravitational influence on visible matter. The so-called dark matter seen in the outer reaches of galaxies and within clusters may very well be made up, at least in part, of these stellar remnants.

It may be timely to mention that the recent data on distant x-ray clusters obtained from XMM and Chandra projects indicate that the observed abundances of clusters at high redshift, taken at face value, give $0.9 < \Omega_{m0} < 1.07$ (at 1σ) (Blanchard 2005). This favours a matter-dominated model and is consistent with the value of Ω_{m0} in the QSSC estimated from the SNe Ia and CMB observations. However, it is hard to reconcile with the concordance model.

5. Conclusion

In order to explain the current observations in the framework of the standard cosmology, one has to trust a preposterous composition for the constituent of the Universe which defies any simple explanation, thereby posing probably the greatest challenge theoretical physics has ever faced. We think this is the right time to seriously consider alternative theories which present more natural explanations to the observed phenomena, especially when there is neither independent observational evidence for non-baryonic dark matter, dark energy and inflation, nor have they a firm basis in a well-established theory of particle physics. Furthermore, it is always necessary for healthy science to have an alternative model to the dominant paradigm.

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Appendix

The *Bayes factor* is a ratio of average likelihoods (rather than the maximum likelihoods used for model comparison in frequentist statistics) for two models M_i and M_j, and is given by

$$B_{ij} = \frac{\mathcal{L}(M_i)}{\mathcal{L}(M_j)} \equiv \frac{p(D|M_i)}{p(D|M_j)}, \tag{A.1}$$

where the likelihood for the model M_i, $\mathcal{L}(M_i)$ is the probability $p(D|M_i)$ to obtain the data D if the model M_i is the true one. For a model M_i with free parameter, say, α and β (generalization for the models with more parameters is straight forward), this probability is given by

$$\mathcal{L}(M_i) \equiv p(D|M_i) = \int \mathrm{d}\alpha \int \mathrm{d}\beta \; p(\alpha|M_i) p(\beta|M_i) \mathcal{L}_i(\alpha, \beta), \tag{A.2}$$

where $p(\alpha|M_i)$ and $p(\beta|M_i)$ are the prior probabilities for the parameters α and β respectively, assuming that the model M_i is true. $\mathcal{L}_i(\alpha, \beta)$ is the likelihood for α and β in the model M_i and is given by the usual χ^2-statistic:

$$\mathcal{L}_i(\alpha, \beta) = \exp\left[-\frac{\chi_i^2(\alpha, \beta)}{2}\right]. \tag{A.3}$$

For flat prior probabilities for the parameters α and β, i.e., assuming that we have no prior information regarding α and β except that they lie in some range $[\alpha, \alpha + \Delta\alpha]$ and $[\beta, \beta + \Delta\beta]$, we have $p(\alpha|M_i) = 1/\Delta\alpha$ and $p(\beta|M_i) = 1/\Delta\beta$. Hence the expression for the likelihood of the model M_i reduces to

$$\mathcal{L}(M_i) = \frac{1}{\Delta\alpha} \frac{1}{\Delta\beta} \int_{\alpha}^{\alpha+\Delta\alpha} \int_{\beta}^{\beta+\Delta\beta} \exp\left[-\frac{\chi_i^2(\alpha, \beta)}{2}\right] \mathrm{d}\beta \, \mathrm{d}\alpha. \tag{A.4}$$

The *Bayes factor* B_{ij}, given by (A.1), which measures the relative merits of model M_i over model M_j, is interpreted as follows (Drell *et al.* 2000; John & Narlikar 2002; and the references therein). If $1 < B_{ij} < 3$, there is an evidence against M_j when compared with M_i, but it is not worth more than a bare mention. If $3 < B_{ij} < 20$, the evidence against M_j is definite but not strong. For $20 < B_{ij} < 150$, this evidence is strong and for $B_{ij} > 150$, it is very strong.

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