From Magnitudes and Redshifts of Supernovae, their Light-Curves, and Angular Sizes of Galaxies to a Tenable Cosmology

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ABSTRACT

Early physical cosmologies were based on interpretations of the cosmic redshift for which there was insufficient evidence and on theories of gravitation that appear to be falsified by galactic dynamics. Eventually, the big bang paradigm came to be guarded against refutation by ad hoc hypotheses (dark matter, cosmic inflation, dark energy) and free parameters. Presently available data allow a more satisfactory phenomenological approach. Using data on magnitude and redshift from 892 type Ia supernovae, it is first shown that these suggest that the redshift factor (1 + z) is simply an exponential function of distance and that, for "standard candles", magnitude $m = 5 \log[(1 + z) \ln(1 + z)] + \text{const.}$ While these functions are incompatible with a big bang, they characterize certain tired light models as well as exponential expansion models. However, the former are falsified by the stretched light curves of distant supernovae and the latter by the absence of a predicted 1+z increase in the angular sizes of galaxies. Instead, the observations suggest that physical processes *speed up* and objects *contract* uniformly as an exponential function of time, standards of measurement not excluded, and only free waves being excepted. Distant events proceed, then, more slowly, while angular sizes remain unaffected, approximately as observed. Since all objects contract in proportion, the Universe retains a static appearance. A corresponding physical theory, which should also explain galactic dynamics, remains yet to be derived from first principles. A way to do this, satisfying also Mach's principle, is vaguely suggested.

Key words: history and philosophy of astronomy – cosmology: observations – cosmology: theory – supernovae: general

Running head: From observations to a tenable cosmology

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1. INTRODUCTION

The first physical model of an expanding universe was presented by Lemaître (1927), who already knew that the redshift $z = (\lambda - \lambda_{em})/\lambda_{em}$ in the light from galaxies increases with their luminosity distance (Livio 2011). This relationship was described as a linear one by Hubble (1929) and, more reliably, by Hubble & Humason (1931). We shall refer to this redshift phenomenon as the "cosmic redshift". If it is interpreted as a Doppler shift, it is clear that the galaxies are rushing away from each other. This interpretation was adopted by Lemaître, but his model (of 1927) was not yet a big bang (BB) model. It assumed eternal expansion from an initial state, at $t = -\infty$, such as described by Einstein's (1917) model of an eternal but spatially closed universe.

Until then, most natural philosophers considered the Universe as eternal, while there had long been a split opinion concerning its spatial extension. According to one, the world is spatially confined, and it was popularly thought of as surrounded by a solid firmament with stars fixed on it. The competing conception of an infinite universe, which perpetually regenerates itself and which contains infinitely many similar worlds, is also ancient. It was argued for by Epicurus, as communicated by Lucretius in *De rerum natura*.

In the BB paradigm, the Universe is assumed to be finite in age and to have come into being in an explosion either out of nothing or, in any case, out of a state to which physics does not apply. It represents one of the alternatives offered by Friedmann (1922, 1924), whose analysis suggested that Einstein's general relativity theory (GR) allows for expanding as well as for contracting universes, but not for a static one, unless a well-tuned repulsive cosmological constant (Λ) is introduced. Einstein's own model (1917) relied on such a constant, which Einstein had introduced reluctantly, since it does not reflect anything known from physics.

The interpretation of the cosmic redshift as a Doppler shift arose within the frame of a Newtonian conception of the Universe in which galaxies were thought of as receding from each other in a Euclidean space. Within GR based cosmology, galaxies are thought of as essentially remaining at rest in an expanding space that brings light waves to expand with it. It can, however, be questioned whether the approach is entirely consistent, since standards of lengths, such as the meter, which is defined in terms of light waves, are assumed not to participate in the expansion of the space that they occupy.

An alternative interpretation was based on the assumption that light loses energy on its way to us. As for the processes suggested to cause the loss, there has been much variation, e.g. a gravitational analogue of the Compton effect (Zwicky 1929), photon-photon interaction in an assumed background radiation field (Finlay-Freundlich 1954, Born 1954), an "aging" of photons (de Broglie 1966), an effect of space curvature (Crawford 2006), interaction with intergalactic plasma, etc. (LaViolette 1986, Marmet & Reber 1989, Assis & Neves 1995, Sorrell 2009). Doubts have been raised against all of these proposals. Most of the mechanisms would lead to some blurring of images and a frequency dependence of z, but it is questionable whether the presence or absence of such effects has ever been demonstrated conclusively.

The tired light (TL) hypothesis had to face a fatal argument only more recently, when it was discovered that the light curves of distant supernovae of type Ia were stretched in proportion to the redshift factor 1+z (Leibundgut et al. 1996, Goldhaber, et al. 1997, 2001, Riess 1997, Filippenko & Riess 1997, Perlmutter 1998, Foley et al. 2005, Blondin et al. 2008). Theories in which periods of light are lost to the extent to which the remaining ones expand do not predict this time dilation effect.

Bondi & Gold (1948) argued that only in a universe that is homogeneous and unchanging on the large scale, i.e., in which their "perfect cosmological principle" holds, there is any basis for the assumption that the laws of physics are constant. Since they also interpreted the cosmic redshift as a Doppler shift, they were led to the steady-state theory, in which creation (out of nothing) is an on-going process by which the matter density in an expanding universe is kept constant. This sets the steady-state theory (Bondi & Gold 1948, Hoyle 1948) apart from Epicurean cosmology, in which the perfect cosmological principle was also implied, while creation out of nothing was considered as impossible.

The steady-state theory gradually lost the attractiveness it may have had initially, and it was out-competed by the BB paradigm when it did not offer a reasonable explanation for the cosmic microwave background radiation (CMBR). While the steady-state theory was open to falsification by observations, the BB paradigm could be retained whenever unexpected observations turned up. Each time it was possible to save it by introducing a suitable ad hoc hypothesis, i.e., a "fudge factor". Some of these arose immediately as rational conclusions that could be drawn if the paradigm was accepted a priori. Others were more inventive. The most prominent were 1) dark matter, 2) cosmic inflation, and 3) dark energy. To these must be added that the magnitude of the apparent size evolution of galaxies remains unexplained.

Dark matter was suggested by the super-Newtonian cohesion of galaxy clusters (Zwicky 1933, 1937) and of individual galaxies (Rubin, Ford & Thonnard 1980). The hypothesis that unseen matter is responsible for this is reasonable and compatible with known physics. This holds for ordinary baryonic matter in form of gas, dust and substellar objects. "Hot dark matter" in form of neutrinos with non-zero rest mass might also contribute. More questionable is the purely hypothetical cold dark matter in form of exorbitant amounts of weakly interacting massive particles (WIMPs), which ought to be present mainly in halos around galaxies, but which escape observation by any independent means. According to a recent analysis (Kroupa 2012), dark matter cannot bring concordance cosmology into agreement with the whole set of relevant astronomical data. Alternative approaches are represented by theories such as Milgrom's modified Newtonian dynamics (MoND) (Milgrom 1983, 2002, Bekenstein 2004, Famaey & McGaugh 2012) and other approaches with the same objective (Moffat 2005). MoND does not offer an *ab initio* understanding of the phenomenon, but it models the cohesion of all kinds of galaxies successfully in terms of a single function, while galaxy clusters still pose problems (Sanders 2003).

Cosmic inflation (Guth 1981) is a theoretical construct outside the realm of known physics. It was introduced in order to reconcile the fact that the Universe appears flat, clumpy and yet homogeneous on the largest scale with an initial event in conformance with the BB paradigm, in which such a universe would be an extremely unlikely outcome. It increases the likeliness of such an outcome by assuming physics to have been expediently different from what is known when the universe had not yet reached an age of 10^{-32} s. The whole approach and even its logical conclusiveness are still under debate even among those who proposed it (Steinhardt 2011).

Dark energy is a form of energy whose effects can be captured by Einstein's cosmological constant Λ but whose properties transcend the realm of known physics. The cosmological constant was reintroduced because it appeared to make the observed magnitude-redshift relation of distant type Ia supernovae compatible with the BB paradigm (Riess 1998, Perlmutter 1999, Peebles & Ratra 2003). In the absence of any grounding in empirical knowledge of nature, dark energy stands out as a supernatural entity, while the dark matter zoo houses both natural and supernatural species.

Size evolution of galaxies: all BB models predict the angular sizes of galaxies beyond a certain distance to increase. Astronomical investigations have not shown such an increase to be present, but if the BB paradigm is nevertheless taken for granted, this just makes it obvious that galaxies were smaller in the past. Some evolution of galaxies is to be expected within the BB paradigm, but it is unexpected and thought provoking that the apparent growth of galaxies happens to keep their sizes in proportion to the size of the expanding universe (van der Wel 2008).

"Dark flow" is a label that has been attached to the large-scale coherent motion of galaxy clusters, which transcends the boundaries of gravitational binding in an expanding universe and therefore has been tentatively ascribed to influences from pre-inflationary inhomogeneities (Kashlinsky et al. 2008).

A critical attitude towards the BB paradigm is already motivated by the fact that the paradigm involves initial conditions that defy physics. By relying on the fudge factors that have become part of the ΛCDM concordance model, this approach has turned into a highly speculative doctrine that tends to blind adherents by the shine of its quantitative precision, in particular in modeling the CMBR anisotropies. The model is often claimed to "explain" certain data while its success is actually due to free parameters that have been adjusted to fit the data without being understood. In bare fact, classical mechanics (CM) and GR stand as falsified at the scale of galaxies and larger structures, and the fudge factors in addition to dark matter reflect further ignorance that is likely to involve a misunderstanding of the cosmic redshift.

In the present paper, astronomical observations of redshift, time dilation, magnitude, and angular size will be subjected to phenomenological analysis and confronted with predictions by theories that represent alternative traditional interpretations of the cosmic redshift. It will be shown that the observations call for a cosmology that is different from the BB paradigm as well as from all the considered alternatives.

2. METHOD

Since CM and GR, on which the BB paradigm relies, stand as falsified already in the face of galactic dynamics, these theories cannot be considered to constitute a reliable basis for cosmology. It is, in fact, also justified to ask whether they are adequate for everyday physics. In these theories, inertial motion cannot be rationally explained since it is introduced by axiom, and no theory can explain its own axioms. They also require us to consider an inertial force such as the centrifugal force, whose reality is beyond any doubt, as fictitious if regarded from a co-moving frame of reference. This rather suggests that it is the linkage in these theories between inertia and space (instead of the matter in the Universe) that is fictitious.

The present phenomenological approach relies on inferences drawn from astronomical observations on the basis of more generally valid physical and geometrical considerations alone. The predictions of two broad classes of cosmological theories will be confronted with the observations:

1. "Tired light" theories, in which it is assumed that *photons loose some of their energy* on their way through a static space, which implies a wavelength increase. The Universe is assumed to be sustainable.
2. Expansion theories, in which the redshift is assumed to be due to relative motion or an expansion of 'space'. The expansion is described by a scale factor $R(t)$ that increases with time. While its relation to z varies between models, $R(t) = (1 + z)^{-1}$ holds in approximation for $z < 1$ in all. The BB models of either conception constitute a specific subfamily of this type, in which the Universe is assumed to be transient.

There are inherent problems with both expansion theory conceptions. In the first one, relative velocities > c can arise. In the second one, light waves are stretched because *space* expands, but if this were to hold in general, the standard of comparison for wavelengths would also be stretched in proportion to the light waves, so that no expansion would be observed. This holds as well for the duration of periods, since these are linked to the corresponding wavelengths by c, which is constant by definition. An exceptionless expansion or contraction of space has no observable physical consequences since it is just a rescaling that is neutralized by the same rescaling of the standards of measurement. Masreliez' (2004) expansion theory, which has sprung from concerns with the deficiencies of the BB paradigm like to those mentioned here in section 1, shares this problem. It is said to be scale-invariant due to expansion without exception, but its prediction of a redshift rests nevertheless on a tacit assumption that standards of measurement do not expand. In expansion cosmologis, it is actually assumed that, in the present epoch, structures participate in a cosmic expansion to the extent to which this is not prevented by forces, and in evaluating these theories, we shall also make this assumption.

In TL models, it has often been assumed by evaluators (Tolman 1930), advocates (Sorrell 2009) and critics (Lubin & Sandage 2001) that no photons are lost in transmission. The flux F (alias "apparent luminosity" l) from a source would then only be reduced by $(1 + z)^{-1}$, but this is questionable a priori. If a redshift arises without an increase in the distance between source and observer, some periods of the redshifted radiation must be absorbed, reflected or deflected per unit of time because they do not all fit into the given spacetime interval. By this loss, which also explains the absence of time dilation, F is reduced by a further factor of $(1 + z)^{-1}$. Exceptions would be processes that cause only minimal deflection of the radiation (blurring of images) and those that cause additional dimming. If the flux is reduced by $(1 + z)^{-1}$, the effective solid angle of a black body radiator needs to increase as $(1 + z)^3$ in order for its surface brightness to be compatible with Planck's law. This defines the minimal deflection. The required increase in solid angle is only $(1 + z)^2$ if the flux is reduced by $(1 + z)^{-2}$. Although stars are approximate black bodies, those in distant galaxies remain in any case point-like and their blurring does not measurably affect the apparent size of galaxies.

Since no TL model has found wider acceptance and the accounts for their flux functions are often deficient or absent, we shall test both the traditionally assumed flux reduction by $(1 + z)^{-1}$ and the modified one, by $(1 + z)^{-2}$.

In expansion cosmologies, there is time dilation, and in this case it is generally assumed that the energy $h\nu$ of each observed photon is reduced to $h\nu(1 + z)^{-1}$ while the number of photons arriving per unit of time is also reduced by the same factor. In this case, the flux will likewise be reduced by $(1 + z)^{-2}$.

The types of astronomical observations whose relation to the cosmic redshift will be considered are primarily the following:

- Flux (of type Ia supernovae). Its relation to the redshift distinguishes between different alternatives within each type of theory, i.e., between models of type 1 with different flux reduction functions as well as between models of type 2 with and without a big bang.
- Time dilation (in the light curves of type Ia supernovae). This is predicted by all models of type 2 in distinction from those of type 1.
- Angular size (of galaxies and larger structures). While models of type 1 predict angular sizes such as in a static Euclidean geometry, those of type 2 predict them to be enlarged by a factor of $(1 + z)$ in a flat space.

This serves the purpose of arriving at an interpretation of the cosmic redshift that is compatible, without invoking any fudge factors, with all three of the mentioned types of astronomical observations. Additional phenomena of cosmological importance, such as gravitational binding and background radiation, will be considered more rudimentarily.

3. PREDICTIONS

3.1. Redshift

In a TL universe as well as in an exponentially expanding universe, the factor λ/λ_{em} by which waves are stretched per unit of distance is constant and everywhere the same. The redshift is described by an exponential function of Euclidean distance *D*. In cases in which no other mechanism contributes to the redshift, we have

$$z = \exp(\frac{H}{c} D) - 1, \qquad (1)$$

where *H* is the Hubble constant, i.e., the Hubble parameter (unit s^{-1}, practically km s^{-1} Mpc^{-1}) remains constant. For moderate distances that transcend the gravitational well of the local group of galaxies, *z* varies approximately in proportion to *D*. Inverting equ. (1), the distance D_z of an object, estimated on the basis of *z*, can be calculated as

$$D_z = \frac{c}{H} \ln(1+z). \qquad (2)$$

These expressions for *z* and D_z differ from the more complicated ones that are valid in BB models. These are marked by a finite maximum value for *D*. At high redshifts, this leads to substantially different predicted relations between redshift and other observables, such as the apparent magnitude of type Ia supernovae. If the exponentiality of the expansion is confirmed, it will not be necessary to delve into the various redshift-distance relations in BB models or any other imaginable alternatives to exponential expansion.

3.2. Time dilation

In expanding universe theories, each wave of light is emitted from a position farther from the observer than the previous one, so that successive waves will arrive at the observer with an increasing delay. This *Doppler effect* causes waves to stretch together with any modulation they may carry. A pulse of light whose duration is *T* in the rest frame of the source will have duration $(1 + z)T$ in the rest frame of the observer, and the light curves of supernovae are affected in proportion.

TL theories predict no time dilation and so no stretched light curves. In principle, a mechanism that causes the periods of the frequency components in the spectrum of light all to be modified by the same factor also causes the periods of the components that describe its amplitude modulation, such as light curves, to be modified by the same factor. In order for time dilation to be absent, periods of light must be lost to the same extent to which the remaining ones expand. This is what happens in a universe that does not offer the extra distance in space and time that would be required in order to accommodate expanded periods.

3.3. Flux

In a static and flat universe in which light is not subjected to any frequency shift, the intensity (W m^{-2}) of the light received from an object, such as a star or galaxy, decreases with the square of the distance from it, i.e., the flux *F*, defined as the energy that flows across unit area normal to the line of sight per unit of time, varies with distance *D* as $F \sim D^{-2}$. In expansion cosmologies, the relation between flux *F* (or "apparent luminosity") and absolute luminosity *L*, defined as the total power radiated by the object, is modified by the expansion. If both the energy of each photon and the number of photons arriving per unit of time are reduced by factors of $(1 + z)^{-1}$ and if, in distinction from BB models, there are no additional factors invlolved, this gives us

$$F = \frac{L}{4\pi D^2 (1+z)^2}\,, \qquad (3)$$

so that the distance of an object, estimated on the basis of its flux,

$$D_F \sim \frac{1}{\sqrt{F(1+z)^2}}\,, \qquad (4)$$

which takes the effect of the redshift into account. This D_F must not be confused with the "luminosity distance" D_L, which is defined such that $D_L^2 = L(4\pi F)^{-1}$, where the effect of the redshift is ignored.

In terms of astronomical magnitude m and absolute magnitude M, defined as the equivalent magnitude at a distance D_M of 10 pc, this corresponds to a distance modulus

$$m - M = 5\log\left[(1+z)\frac{D}{D_M}\right], \qquad (5)$$

and D_m, which is an estimate of D based on magnitude m, can be calculated in pc as

$$D_m = \frac{10^{(\frac{m-M}{5}+1)}}{1+z}\,. \qquad (6)$$

In the TL model considered by Tolman (1930), $F \sim D^{-2}(1+z)^{-1}$. In this case, we have a factor of $(1+z)$ in the denominator of equ. (3) instead of $(1+z)^2$. With $F \sim D^{-2}(1+z)^{-2}$, as suggested in section 2, equs. (3) to (6) are valid in TL models as well.

3.4. Angular size

In a static Euclidean universe, the angular size δ of an object is $\delta = 2\arctan(d/2D)$, where d is a diameter (e.g., major or minor axis of a galaxy) and D the distance to the object. In small-angle approximation

$$\delta \approx d/D. \qquad (7)$$

In TL theories, equ. (7) can be assumed to hold in close approximation for galaxies and galaxy clusters. Blurring can cause the effective δ of individual stars to become substantially larger, but in practical astronomy, the individual stars in distant galaxies remain point-like sources of radiation.

Expansion theories predict the angular sizes of all coherent objects (stars as well as galaxies) to be enlarged in inverse proportion to the scale factor $R(t) = (1+z)^{-1}$. Thus, they predict δ to vary as

$$\delta \approx (1+z)d/D, \qquad (8)$$

where D is the comoving distance, $D = (1+z)D_A$. The "angular distance" D_A of an object is defined as the distance at which the object with its observed δ would be in a static Euclidean universe. Confirmation of the 1+z increase in angular size of distant galaxies as a function of redshift (equ. 8) would be tantamount to a confirmation of the reality of this expansion, provided that there is no evolution of $d(z)$.

4. ASTRONOMICAL OBSERVATIONS

4.1. Redshift, magnitude, and distance

The relation between D_m (equ. 6) and D_z (equ. 2) is shown in Fig. 1 for supernovae of type Ia, assuming $M = -19.3$. The data include the *SALT2* analysis of the *Constitution* set (Hicken et al. 2009), the *Union2* set (Amanullah 2010), and the *SNLS-3* set (Guy et al. 2010). In cases in which the same object occurred in more than one of these sets, the data from the analysis that reported the least uncertainty in m were used. No data were excluded for any other reasons. The object with the largest redshift, SN 1997ff, whose data are somewhat uncertain, was added from Riess et al. (2001). This made a total of 892 objects.

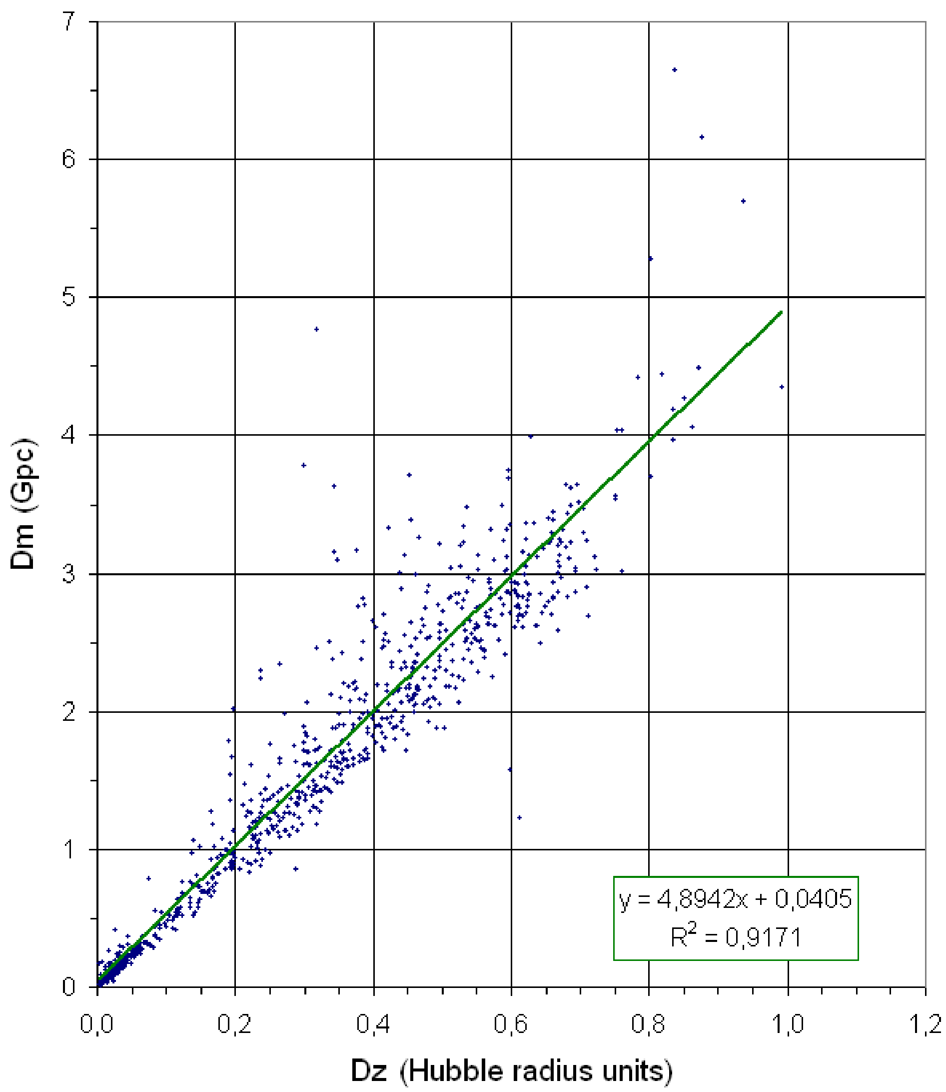

Figure 1. Magnitude based distance D_m in Gpc (equ. 6) vs. redshift based distance D_z in Hubble radius units (equ. 2) for 892 supernovae of type Ia, with a linear regression line. Data from Constitution set (Hicken et al. 2009, SALT2), Union2 set (Amanullah 2010), SNLS-3 set (Guy et al. 2010), and SN 1997ff from Riess et al. (2001).

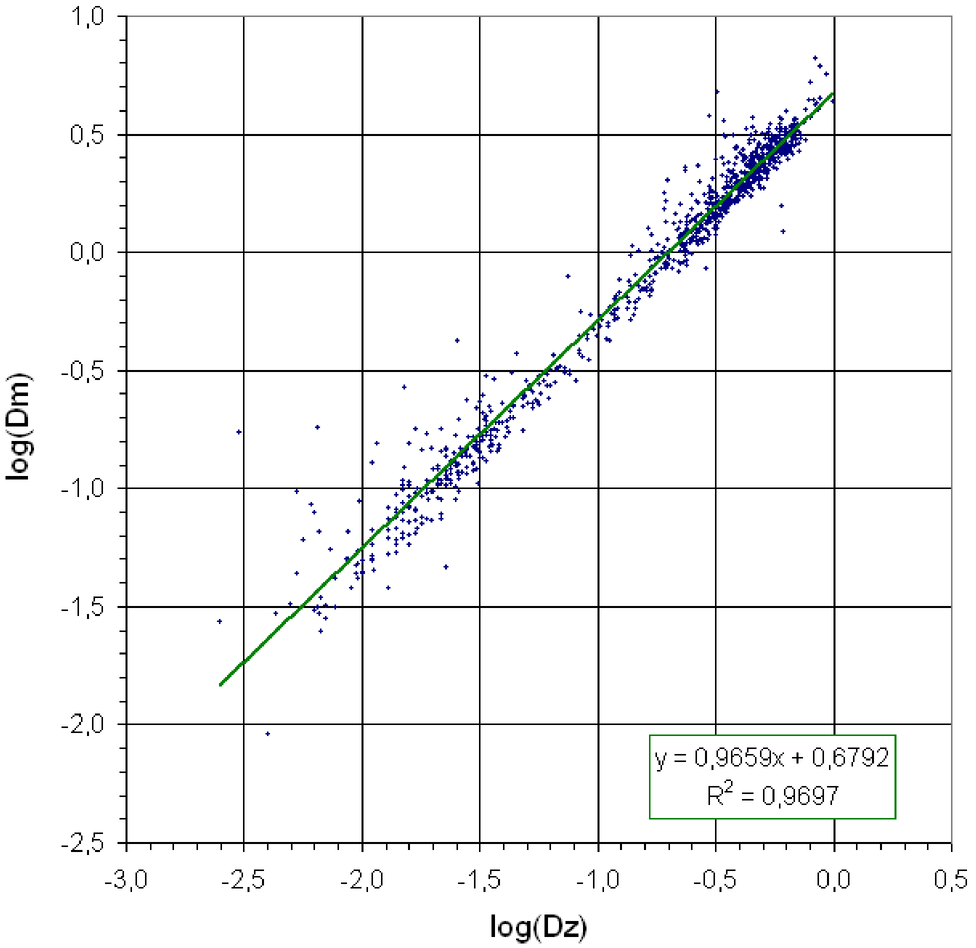

Figure 2. log(D_m) vs. log(D_z) for the same 892 supernovae of type Ia as those in Fig. 1, with a linear regression line.

A linear regression line fitted to the data is also shown in Fig. 1. The variance explained by it is only moderately high (R^2 = 0.92), but it can also be judged that this could not be improved substantially by introducing a reasonable non-linearity. For the Hubble radius *c/H*, i.e., at D_z = 1, a value of D_m = 4.93 Gpc is obtained. This corresponds to a Hubble constant H = 60.8 km s^{-1} Mpc^{-1}. Since these values vary with the assumed value of *M*, they are only marginally informative.

If equs. 6 and 2, on the basis of which the values of D_m and D_z have been calculated, are correct, whatever the true value of *H*, there will be a linear relation with slope = 1.0 between log(D_m) and log(D_z). The observed relation is shown in Fig. 2.

A linear regression analysis with log(D_z) as the predictor and log(D_m) as the predicted variable results in R^2 = 0.9697 and so leaves just 3.03% of the variance unexplained. The slope of the regression line is 0.9659 (standard error 0.0057) and its intercept 0.6792 (standard error 0.0057). The intercept corresponds to a Hubble radius of 4.78 Gpc. The slope, which is crucial here, turns out to be close to 1.0, but the small discrepancy is still significant. A discrepancy like this one is to be expected because of the Malmquist bias in the data. Such a bias is clearly present in several of the original data sets that have been pooled here, but there is no evidence for it among the few most remote objects, which have all been observed with the Hubble space telescope. The effect of the Malmquist bias on the slope of the regression line is very much reduced in the pooled data, but there remains a trace.

Any Malmquist bias can be aptly avoided by choosing $\log(D_m)$ as the predictor and $\log(D_z)$ as the predicted variable. This results in the same value of R^2 as in the reverse case, but now the slope turns out to be 1.0040 (standard error 0.0059). Since this is within one standard error from the predicted 1.0, the discrepancy is not significant. The most extreme outliers are two objects at $\log(D_z) \approx -2.5$ and -2.2 whose light appears to have been heavily dimmed. If these are removed, the slope of the regression line is brought from 1.0040 to 1.0001, but R^2 is only marginally improved to 0.9744.

Fig. 2 does not suggest that the prediction errors might be due to a non-linearity in the relationship. It can be noticed that the residuals are increased among the objects that are closest to us, even if outliers are disconsidered. This may be due to peculiar motions, whose contributions to the *z*-values will be noticeable in this range.

There is positive skewness in the residuals of $\log(D_m)$. This suggests that the observations in some cases have been affected more or less by dimming. With allowance for this, more than 99% of the objects may be good standard candles. The six outliers whose *m* was clearly higher than expected, with $\log(D_m)$ far below the regression line in Fig. 2, represent extraordinary events of some kind.

The result of the regression analysis of $\log(D_z)$ predicted from $\log(D_m)$ fits the data so well that there remains no room for a significant improvement. It confirms that the ratio between D_m (equ. 6) and D_z (equ. 2) of 'standard candles' is constant over the whole range of distances. From these equations, we can calculate that

$$m = 5 \log[(1 + z) \ln(1 + z)] + const, \qquad (9)$$

which is an exact expression of the condition under which this constancy is obtained. The data are in excellent agreement with those TL models in which equs. 3 to 6 hold since $F \sim D^{-2} (1 + z)^{-2}$, as well as with those expansion models in which the redshift factor is simply an exponential function of Euclidean distance, as in equ. (1) and (2). This is the case in Masreliez' theory (2004), but it is not the case in any models within the big bang paradigm. Equ. (9) does not either hold in TL models in which $F \sim D^{-2} (1 + z)^{-1}$, as traditionally assumed. We shall consider these and any other models that fail to satisfy equ. (9) as falsified.

It is well known that there is a substantial discrepancy between SN Ia data such as these and the predictions within the frame of the BB paradigm: distant SNe Ia are less luminous or less redshifted than predicted (Riess 1998, Perlmutter 1999, Peebles & Ratra 2003). If the scientific method is strictly followed, such a discrepancy leads to a rejection of the theory unless it can be shown that the discrepancy may be due to a known effect that has been neglected. Since such an effect has not been identified in this case, the theory is to be rejected. If, instead, the established doctrine is to be defended, the discrepancy can be brought down to an acceptable level by reintroducing the cosmological constant Λ as a free parameter. For compatibility with the supernova data, this requires the Universe to be dominated by "dark energy" ($\Omega_\Lambda \approx 0.7$), which is an imaginary or 'supernatural' form of energy, otherwise unknown in the physical world. The discrepancy can be removed completely if Λ is allowed to vary as a function of time. However, all this comes at the cost of increased complexity - calculating $m(z; \Omega_M, \Omega_\Lambda)$ requires numerical integration - and the loss of explanatory power. In this approach, it is possible that the prediction can even be brought to fit the data slightly better than equ. (9), but then it will stand out as an inexplicable and thought provoking coincidence that this simple equation also describes the data so well. Occam's razor will do its service.

In the following, we shall consider analyses performed within the prevailing BB paradigm and with traditional assumptions about TL as far as they remain valid or can easily be translated into a model that is not already falsified by the SN Ia test.

4.2. Redshift and time dilation

The light curves of distant type Ia supernovae, which describe their flux as a function of time, appear to be stretched by time dilation in proportion to the redshift factor (Leibundgut et al. 1996, Goldhaber et al. 1997, 2001, Riess et al. 1997, Filippenko & Riess 1998, Perlmutter et al. 1998, Foley et al. 2005). Advocates of TL were not convinced of this interpretation (Brynjolfsson 2006, Crawford 2009), because the width of the light curves of low-redshift SNe Ia is positively correlated with peak luminosity (Phillips 1993). The apparent time dilation in more distant SNe might thus reflect a selection effect (Malmquist bias).

Blondin et al. (2008) solved this problem by investigating the apparent aging rate of SNe on the basis of their spectra. The spectra of SNe Ia spanning a range of luminosities evolve uniformly over time and, except in a few recognizable outliers, in such a way that the age of a SN Ia can be determined with sufficient accuracy from a single spectrum, without reference to the light curve. In this way, Blondin et al. demonstrated time dilation by a factor of approximately $(1 + z)$ to be unambiguously present.

Against this background, it came as a surprise that time dilation turned out to be absent in the results of Fourier analyses of the luminosity variations of quasars (Hawkins 2010). This needs yet to be explained. In the present analysis, quasars, like gamma ray bursts, are disregarded because their nature is not yet sufficiently understood. This is underlined by the fact that a more specific analysis of luminosity variation in quasars, in which time dilation was implicit, returned consistent results (Dai et al. 2012).

While unknown or poorly understood factors appear to be involved in quasars and also in gamma ray bursts, it is, in any case, evident that TL processes fail to explain the presence of time dilation in SNe Ia, while all expansion theories, including those within the BB paradigm, pass this test. They all predict stretching by the redshift factor.

4.3. Angular size

In cases in which equ. (7) applies, which includes TL models but no BB models, $D = D_A = D_z$ (equ. 2). The approximate empirical relation of $\delta \sim 1/z$ obtained in several older investigations (Kellermann 1972, Sandage 1972, Djorgovski & Spinard 1981) for angular size up to $z > 1.0$ is close to the prediction $\delta \sim \ln(1 + z)^{-1}$ of TL theories.

The same relation had also been observed for the separation of brightest galaxies in clusters (LaViolette 1986). This relation is at variance with expansion theories, which all predict the relation to flatten substantially with increasing z and δ to slowly increase again at large values of z. With exponential expansion, the prediction is $\delta \sim (1 + z)\ln(1 + z)^{-1}$ with a minimum for δ at $z = e - 1$. In the 1970ies, it was still thought that future measurements might show this tendency and so confirm the BB prediction. Meanwhile, there are enough data for galaxies at least up to $z = 3$, and if taken at face value, the expansion theories would have to be rejected on the basis of these (López-Corredoira 2010). However, BB cosmology has come to be widely accepted on faith, and with such an attitude, the data simply make it obvious that galaxies were smaller in the past.

Taking the BB paradigm for granted, Ferguson et al. (2004) found the galaxy radii to scale with redshift approximately as the Hubble parameter $H^{-1}(z)$, i.e., approximately $\sim (1 + z)^{-1}$. They say that “This is in accord with the theoretical expectation that the typical sizes of the luminous parts of galaxies should track the expected evolution in the virial radius of dark matter halos.” However, this is a reasoning about a fudge factor. Hathi, Malhotra & Roads (2006) likewise report that galaxy sizes scale as $H^{-1}(z)$ in the range $3 < z < 6$.

Similar results were also reported by Bouwens et al. (2003, 2004) and Trujillo et al. (2006, 2007). Van der Wel et al. (2008) compared morphologically selected galaxies at $z = 1\pm0.2$

with a sample at z = 0.06±0.02. They found significant size evolution by a factor of two. Together with studies covering different ranges of z, this confirms that galaxy size has to evolve as $R_{gal}(z) \sim (1 + z)^{-1}$ in BB cosmologies. In a final note, they said "*it is remarkable that the change in the sizes of early-type galaxies is consistent with and differs by less than 15% from the change in the scale factor of the Universe, 1+ z. Within the standard cold dark matter scenario this is likely a coincidence since dissipational, strongly non-linear processes that are decoupled from cosmic expansion dominate at the kiloparsec scale of forming galaxies. Nonetheless, we cannot exclude the possibility that there is an underlying, fundamental reason that galaxies are scale-invariant with respect to a comoving coordinate system.*" This is, of course, as expected in a static, sustainable universe, in which there is neither a change in scale factor nor any overall size evolution.

Although this is not made explicit in the quoted papers, the observations of angular size reported in them are close to those predicted by static TL theories. They are hard to reconcile with the assumption inherent in expansion theories, namely that *everything expands to the extent to which this is not prevented by forces.* While the expansion of galaxies is prevented by the force of gravity - they cohere even more than suggested by CM and GR - they must, in the face of these data, nevertheless be assumed to have been smaller in the past and to have expanded proportionally with the universe, so that the theoretical 1+z increase in observable angular size (equ. 8) is not realized.

Williams et al. (2010) describe the evolving relations between size, mass, surface density, and star formation within concordance cosmology in a large set of galaxies by functions of the type $r(z) = b(1 + z)^a$, where r is the equivalent radius. They report a to deviate from –1 as a function of galaxy mass. Similarly, Trujillo et al. (2007) reported results that suggest $a < -1$ in the size evolution of the most massive elliptical galaxies, as distinct from disc-like galaxies. Any true variation in a as a function of galaxy type is at variance with the predictions of theories in which the evolution of widely scattered galaxies is not coordinated, but untrue variation can arise as a result of inappropriate measurements and correction factors. It remains yet to be seen whether the apparent variation in a can be brought into accord with the hypothesis of a static universe. Variation in b does not pose such a problem, but it suggests a contribution by peculiar redshift mechanisms such as gravitational and/or plasma redshift. In the data of Williams et al. (2010), the most significant variation between galaxy types is actually due to differences in b between galaxies that differ in estimated mass, in spectral type, and in relative star forming rate.

It is, in any case, clear that the 1+z increase in angular size, which is predicted by expansion theories (equ. 8) in comparison with static theories (equ. 7), is not observed, and that the data are more compatible with the TL hypothesis.

It order to defend orthodox cosmology, it needs to be shown that the discrepancy may be due to a known process that has been neglected. When Newman et al. (2012) ask whether the size growth of quiescent galaxies could be due to mergers, they do not ask whether a predicted frequency of merging could account for the observed growth. They take orthodox cosmology for granted and ask whether the observed growth could be accounted for by mergers at all. They conclude that these may explain most of the growth at $z < 1$ while unspecified additional physical processes are required at $z > 1$. López-Corredoira (2010) did consider additional processes, but found also these not to be up to the task.

4.4. Predictions vs. observations in summary

The crucial tendencies in the astronomical data and the predictions of the two alternative cosmological models that survive the SN Ia test in section 4.1 can be conveniently described by specifying the exponent in the redshift factor $(1 + z)$ that applies to each measure. This is done in Table 1. In addition to the major observables, the scale factor and some common distance measures are also listed. The exponents entered for flux F and luminosity distance D_L in the static TL model deviate from previous suggestions (e.g., Tolman 1930) as motivated in section 3.3, so that flux does not distinguish by itself between the models.

Table 1. Variation of astronomical variables predicted by the two types of cosmological model mentioned in section 2. Figures listed indicate the appropriate exponent a in $(1 + z)^a$ in each case. An asterisk indicates where models fail. Figures in italics deviate from those in many text books as explained in section 2. Figures in parentheses characterize "hidden contraction cosmology", which is described in section 5 and whose other exponents agree with those listed under "Observation".

Observational variable	Observation (approximate)	Model prediction	
		Static	Expansion
Flux $F \sim D^{-2}(1 + z)^a$	–2	*–2*	–2
Time dilation factor $(1 + z)^a$	1	0*	1
Angular size (galaxies) $\delta \sim (1 + z)^a D^{-1}$	0	0	1*
Large scale gravitational binding	enhanced	normal*	attenuated**
Luminosity distance $D_L = D(1 + z)^a$	(1)	*1*	1
Angular distance $D_A = D(1 + z)^a$	(0)	0	–1

Static models fail for time dilation (as described traditionally also for flux and surface brightness), expansion models fail for angular size (fudge factor size evolution), and both fail for galactic dynamics, expansion models most definitely (fudge factor dark matter, more of it being needed in expansion models). BB models, which are not shown separately in the table, fail in addition for redshift vs. flux (fudge factor dark energy). Unless modified according to section 3.3, TL models also fail for redshift vs. flux.

What we see is angular sizes (of galaxies) such as in a static Euclidean universe in combination with time dilation (in the light curves of SNe) in proportion to a redshift factor that is an exponential function of distance, $(1 + z) = \exp(DHc^{-1})$. In the next section, this will be clarified in a phenomenological model. Finally, it will also be considered that we se enhanced large scale gravitational binding.

5. TOWARDS A TENABLE COSMOLOGY

5.1. Spatio-temporal aspects

The observations summarized in Table 1 call for a model in which there is time dilation, which TL models fail to predict. Despite this, both the redshift vs. distance relation (equ. 1) and angular sizes should be like those in TL models of a static, flat and sustainable universe. While the observed scenario is at variance with BB as well as with TL models, it is not difficult to model without introducing any peculiar assumptions in addition to definitions.

The definitions that are relevant here are those of c as a constant that is everywhere the same and the same in all spatial directions. If we accept a standard of time t as defined by the duration of a certain number of periods of the radiation emitted in a standard atomic process, as in the current definition of the second, a standard of length is given by ct.

We shall assume that the exponents listed in the second column of Table 1 are correct, so that we have for flux $F \sim D^{-2}(1 + z)^{-2}$, time dilation corresponding to $\mathrm{d}t(z) = \mathrm{d}t_o(1 + z)$, and angular size $\delta \sim D^{-1}$ independent of z. We shall also assume that spacetime is flat, which qualifies as a “non-peculiar” assumption.

If there is time dilation in proportion to the cosmic redshift factor in light from a distant source and the spacetime geometry is flat, there must also be a proportional lengthening of spatial distances in the direction of observation as well as in any transversal direction, as considered from an observer’s point of view. This must be so if our definitions are to apply also in the frame of reference of the radiation source.

The relationships are illustrated two-dimensionally in Fig. 3. The graph to the left (Fig. 3a) shows a random distribution of equal-sized discs, which can be thought of as galaxies (not shown to scale). In the graph to the right (Fig. 3b), the distances of the discs from the origin are increased exponentially, and their diameters are increased by the same factor, in order to simulate a scenario in which the same scale factor, $\exp(DHc^{-1}) = (1 + z)$, applies to all dimensions of spacetime. In Fig. 3b, the remote universe stands out as expanded, but as seen from the origin, the angular sizes are the same as in Fig. 3a.

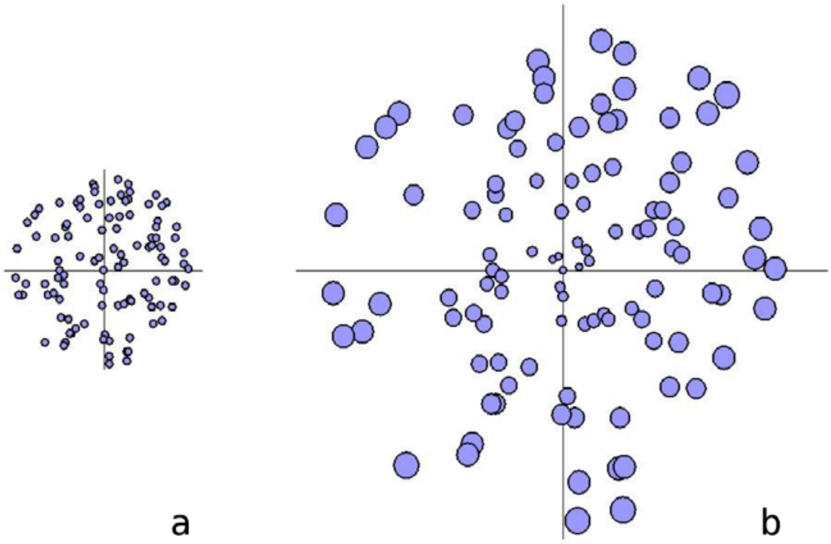

Figure 3. The random distribution of equal-sized discs shown to the left (a) illustrates two-dimensionally a universe in which galaxies are homogeneously distributed. This may be a static tired light universe. To the right (b), the same distribution is shown with the discs and their distances from the origin (within one Hubble radius from it) expanded by a factor of (1 + z) in all dimensions. As seen from the origin, the angular size of the discs is meant to be the same in both graphs. Allow for the disc size quantization introduced by the software used.

A scenario such as illustrated in Fig. 3b does not suggest that the Universe expands. In this picture, all objects in the Universe appear to have been larger in the past. If this is an effect of size evolution, it can only be due to a general *contraction* of physical objects and the Universe itself. Since distances in space are linked to intervals in time by the constant c, this also implies that physical processes speed up, whereby standards and units of time are shortened. This is why we observe redshift and time dilation, which was the starting point of the reasoning that led to Fig. 3b. This figure is expanded in comparison with Fig. 3a since it is scaled in the units of an observer at the origin, which are most contracted but which have been set equal to those in Fig. 3a.

The analysis is actually quite simple. We observe time dilation and redshift in distant objects. This may be due to an expansion of the universe. It may equally well be due to a contraction of our standards of comparison. The angular sizes of distant objects tell us that the *second* alternative is the correct one, since their increase by a factor of $(1 + z)$, which is predicted by the first alternative, is not observed. Further, the observations analyzed in section 4.1 tell us that the cosmic contraction progresses exponentially and causes objects of any size to shrink by a fraction of approximately 6.4 10^{-11} per year in each dimension.

We shall take the emerging conclusion that all objects contract exponentially and in proportion, while light is not affected by this contraction, as the definition of "hidden contraction cosmology". This definition applies in a system of reference with static units of length and time. In an observer's view, the contraction discloses itself only indirectly. It does not cause distant objects to appear as if they came closer. This is so since, during any chosen interval of time, the observer's unit of distance shrinks in proportion to the measured distances. Therefore, there arises no Doppler effect either. In this sense, the contraction is "hidden". Aside from peculiar motions, the universe retains a static appearance in which the past is dilated. The geometric relationships that are illustrated in Fig. 3b are, in its essentials, preserved over time.

If there is an increase in the pace of time and a corresponding contraction of the sizes of all objects, this does not imply that free waves must contract in proportion. If they did, we would have a contraction without exception, which has no observable physical consequences. The cosmic redshift is a metric effect that is entirely due to the contraction of the standards of comparison during the time it takes for the light to reach the observer.

The cosmic contraction may possibly arise as an effect of gravitation. It is well known that a non-expanding, non-rotating universe would collapse due to the gravity of the matter within it (Einstein 1917). Hidden contraction cosmology in fact describes a very slow collapse that goes on forever and everywhere. We shall not delve into the physical detail, since the present approach is just phenomenological. However, even with this restriction, it can be claimed that in a distant planetary system in which CM is valid, the gravitational parameter GM would appear to be enlarged by the redshift factor $(1 + z)$ since its dimensionality is L^3T^{-2}. If the orbital period T in a planetary system in which Newton's laws are valid scales as $(1 + z)$ and the semi-major axis a of the orbit likewise scales as $(1 + z)$, GM must also scale by the same factor:

$$T(1+z) = 2\pi\sqrt{\frac{a^3(1+z)^3}{GM(1+z)}}\,. \qquad (10)$$

In MoND (Milgrom 1983), we have far away from the center of a galaxy an orbital velocity $v = (GM\,a_0)^{-4}$, where a_0 is a critical acceleration. If GM scales as $(1 + z)$, this requires a_0 to scale as $(1+z)^{-1}$ since v must not vary as a function of distance. All accelerations (dimensionality LT^{-2}) scale as $(1+z)^{-1}$ if both L and T scale as $(1 + z)$. We can also consider a system that is bound by charge instead of gravity. In this case, we have to substitute $k_e Q^2 m^{-1}$ for GM in equ. (10), but this alone still does not allow us to tell how G, M, k_e and Q scale individually.

The factors that relate quantities observed at a distance (in some cases indirectly) to local standards of measurement are listed in Table 2, with the purely spatiotemporal quantities listed first. The factors are entered into the next to last column.

5.2. Sustainability

If spatiotemporal quantities appear to be affected in the way described, we can also ask whether and in which sense the contraction appears to affect physical quantities such as mass, momentum, energy, power, the gravitational constant, the Planck constant, etc. This can be answered by considering the conservation laws for mass, energy, linear momentum and angular momentum. These qualify as first principles since they follow from Noether's theorem, which says that there is a conservation law for each continuous symmetry of physical systems. Temporal symmetry is present if the Universe retains a static appearance. It will then be possible to proceed further by a simple dimensional analysis of quantities. Considering that the dimensions are MLT^{-1} for linear momentum and ML^2T^{-2} for energy, we can see that these quantities are conserved if M is conserved, since L and T transform by the same factor. As for flux, it has to be considered that the unit area that figures in it is a local area. It can be noted that the factors for k_e, Q, h, and c, which have been entered into the next to last column of Table 2, have to satisfy the constancy of the fine-structure constant $\alpha = k_e e^2 \hbar^{-1} c^{-1}$. The mentioned equivalence of $k_e Q^2 m^{-1}$ to GM in equ. (10) must also be satisfied. Angles, velocities (angles in spacetime), masses, momenta, energies, and charges are conserved. It is perhaps less expected that the gravitational constant, the Coulomb constant and the Planck constant scale like time and length.

Table 2. Factors that relate observed and inferred quantities to local standards of measurement shown in the third column for the quantities listed in the first. Values entered into the last column show the fraction of the original quantity that is actually transferred to an observer or effective there.

Quantity	Dimensions	Factor distant/local $E_{dist} = E_{loc}$	Transferred by radiation $h = h_{loc}$
Time t	T	$1+z$	
Length l	L	$1+z$	
Angular size θ		1	
Velocity v, c	$L\,T^{-1}$	1	
Acceleration a	$L\,T^{-2}$	$(1+z)^{-1}$	
Gravitational param. $\mu=Gm$	$L^3\,T^{-2}$	$1+z$	
Mass m, Ec^{-2}	M	1	$(1+z)^{-1}$
Momentum M, mv, mc, Ec^{-1}	$M\,L\,T^{-1}$	1	$(1+z)^{-1}$
Energy E, mc^2, hv	$M\,L^2\,T^{-2}$	1	$(1+z)^{-1}$
Power P	$M\,L^2\,T^{-3}$	$(1+z)^{-1}$	$(1+z)^{-2}$
Radiant intensity I_e [Wsr^{-1}]	$M\,L^2\,T^{-3}$	$(1+z)^{-1}$	$(1+z)^{-2}$
Flux F [Wm^{-2}]	$M\,L^2\,T^{-3}L_{loc}^{-2}$	$(1+z)^{-1}$	$(1+z)^{-2}$
Electric charge Q	Q	1	
Impedance V	$Q^{-2}\,M\,L^2\,T^{-1}$	$1+z$	
Planck constant h	$M\,L^2\,T^{-1}$	$1+z$	1
Gravitational constant G	$M^{-1}\,L^3\,T^{-2}$	$1+z$	
Coulomb constant k_e, $(4\pi\varepsilon_0)^{-1}$	$Q^{-2}\,M\,L^3\,T^{-2}$	$1+z$	

If the energy of radiation is conserved and time is dilated by a factor of $(1+z)$, its power will transform as $(1+z)^{-1}$. This appears to be in conflict with the observed flux from SNe Ia, which implies that the power transferred to a sphere centered at the source will be $(1+z)^{-2}$ of the original power, as follows from equ. (3). Mathematically, the conflict is resolved if the Planck constant at the source is considered to be higher by $(1+z)$ as compared with the value it has in the observer's vicinity. The physical problem remains nevertheless, since this still implies that a fraction of $1-(1+z)^{-1}$ of the original energy is lost. If energy is to be conserved, this fraction must still be present in some other form. Considering that the impedance of space must scale as $(1 + z)$, which follows from a dimensional analysis (see Table 2), and that any inhomogeneity in the impedance of a medium will cause some of the radiation passing it to be reflected, and that this will happen again to such reflected radiation, it appears likely that this very gradually progressing loss gives rise to the CMBR. It would exceed the limits of the present approach to delve into the details of this process.

At this point, we can ask the more fundamental question of whether a universe in which energy is transferred from stars into an ocean of “background radiation” with maximal entropy could be sustainable. In order for this to be the case, the same amount of energy that goes into the CMBR must also leave it per unit of time and find its way back into matter. The CMBR cannot loose this energy in form of thermal radiation. Instead, it could be transferred to low-frequency gravitons, whose frequency and energy would increase by interaction with the photons in the same ocean, and the gravitons might drain into all the potential wells in which matter resides and there be absorbed. This is, of course, just a wild speculation about the cosmic energy cycle that must be closed in order for the universe to be sustainable instead of transient.

5.3. Galactic Dynamics

In the face of galactic dynamics, hidden contraction cosmology fares better than expansion cosmology. Instead of a cosmological expansion, by which the gravitational attraction of a galaxy group would be overcome at a zero-velocity surface, it is characterized by a contraction acceleration, $a_{\mathrm{contr}} = cH$, which appears to work in the right direction. However, this a_{contr} has no observable effect if all objects contract in proportion. The rotation curves of galaxies suggest, nevertheless, that a contraction acceleration is in effect, but it is not quite as high and it may be due to reduced inertia.

If a physical cosmology is to be well-founded and based on a theory of gravitation and inertia, this foundational theory must offer a rational explanation for inertia. This is accomplished if it satisfies Mach’s principle. In such a theory, the lesson drawn from the equivalence between a static gravitational force and a force due to uniform acceleration of a body will be different from that which led to GR. It will make it clear that in both cases, the body sees a gradient in the gravitational potential field, which in the rest frame of an accelerated body is due to the acceleration of all the other bodies in the Universe. A Machian theory of induced inertia was attempted by Sciama (1953). In his approach, there was still a substantial missing mass problem, but this may well be solved if the implications of inertia being induced are taken into account ab initio.

If gravitation is propagated by a massive field, then the velocity v_{g} of gravitational waves (gravitons) will depend upon their frequency as $(v_{\mathrm{g}}/c)^2 = 1 - (c/f\lambda_{\mathrm{g}})^2$, and the effective Newtonian potential will have a Yukawa form $\sim r^{-1}\exp(-r/\lambda_{\mathrm{g}})$, where $\lambda_{\mathrm{g}} = h/(m_{\mathrm{g}}c)$ is the graviton Compton wavelength (Will 1998). This wavelength cannot be infinite, and gravitons cannot be massless if the Universe has a finite equivalent gravitational radius R_{g}, which is implicit in the scenario illustrated by Fig. 3b. If inertia is induced by gravitation, it will, then, be reduced at accelerations that are low enough to create gravitational waves whose wavelengths approximate or exceed R_{g}. This is the case at accelerations below Milgrom’s (2002) constant $a_0 \approx 10^{-10}$ m s^{-2}. A theory along these lines has yet to be elaborated.

If inertia is reduced for small accelerations, gravity will appear to be super-Newtonian not only in the outskirts of galaxies and in galaxy clusters, but also for the Universe as a whole. The average density of the Universe will, therefore, be considerably lower than the critical density $\rho_{\mathrm{c}} = 3H^2(8\pi G)^{-1}$ of a flat Friedmann universe with $\Lambda = 0$. This is likely to solve the missing mass problem Sciama (1953) ran into.

If inertia is reduced at small accelerations in the way suggested here, this can be modeled phenomenologically by adding a first order acceleration high-pass function to Newton’s second law. This gives us

$$\mathbf{F} = m\mathbf{a}\frac{\dfrac{a}{a_0}}{\sqrt{1+\left(\dfrac{a}{a_0}\right)^2}}\,. \qquad (11)$$

This is equivalent to Milgrom's (1983) original suggestion of $\mathbf{F} = m\,\mathbf{a}\,\mu(a/a_0)$, where $\mu(x)$ was an unspecified interpolation function in which $\mu = 1$ if $x >> 1$ and $\mu = x$ if $x << 1$. The function $\mu(x) = x(1 + x^2)^{-1/2}$, which appears in equ. (11), has been shown to work well for galaxy rotation curves (Sanders 2003, Famaey & McGaugh 2012).

6. GENERAL DISCUSSION

In this paper, it has been shown that for standard candles it holds that magnitude $m = 5\log[(1 + z)\ln(1 + z)] + const.$, which suggests that the redshift factor (1 + z) is simply an exponential function of distance, $(1 + z) = \exp(DHc^{-1})$, and that flux $F \sim D^{-2}(1 + z)^{-2}$. The exponential function is at variance with a BB event and the flux with TL models in which $F \sim D^{-2}(1 + z)^{-1}$, but it has been argued that $F \sim D^{-2}(1 + z)^{-2}$ would be more reasonable for TL as well. While such a TL model would also be in sufficient agreement with the observed angular sizes of galaxies, it must likewise be rejected since it fails to predict time dilation in the light curves of SNe. Instead, the evidence has been shown to indicate that physical processes speed up and objects of all sizes contract exponentially, only free waves remaining unaffected, in which case the Universe retains a static appearance while exposing time dilation in distant objects and angular sizes such as in a Euclidean geometry. Subsequent to a continued phenomenological analysis, in which conservation laws, the CMBR and the sustainability of such a universe have been considered, it has been suggested that a quantum theory of induced iniertia may have the potential of explaining galactic dynamics and the low mass density of the Universe without depending on ad hoc assumptions.

Although the thesis that a theory should be considered as scientific only if it is open to falsification (Popper 1935) has found acceptance in many disciplines, physical cosmology continued to be committed to established theories and ideas that were treated as beyond criticism. CM and GR are well-proven on a terrestrial scale. When the cohesion of galaxies and galaxy clusters was observed to be *stronger* than predicted, this should have been taken as a falsification at these scales, unless it could be shown on independet grounds that much more matter must be present. When, more recently, it looked as if the cohesion of the Universe as a whole was *weaker* than predicted by BB cosmology, this should again have been taken as a falsification, unless it could be shown that the discrepancy is due to a known physical cause that had been neglected. Einstein's Λ is just a mathematical possibility that is not known to reflect anything in nature. It was clear already prior to the reintroduction of Λ that BB cosmology had lost its openness to falsification when its tenability failed to be put into question by the mainstream when the search for the predicted increase in angular sizes at large redshifts (Kellermann 1972) had remained negative and when the consistency problems that were attempted to be remedied by cosmic inflation (Guth 1981) had been noticed.

While the uncritical perseveration of traditional paradigms is typical of what Kuhn (1962) in his study of the sociology of science called "normal science", cosmology demonstrates instructively how this practice can lead a discipline into a veritable dark age if the paradigm is *ill-founded.* This ill-foundedness can be traced back to Newtonian mechanics, which fails to offer a rational explanation for inertia. In Einstein's GR, this deficiency in explanatory power is even extended in scope. What should be strived for instead is a theory of gravitation and inertia that rests firmly on first principles. These are principles that are generally accepted even outside the frame of the particular theory. Only such well-founded theories make us understand phenomena ab initio. Any theory that rests on a crucial assumption or postulate that is not rooted outside the domain of the theory itself remains speculative, conditional and provisional. It remains ‘just a theory’.

The considerations detailed in the present paper may have made it clear that neither BB cosmology nor the considered alternatives satisfy the mentioned desiderata. Since hidden contraction cosmology is just phenomenological, like Kepler’s laws and Milgroms’s MoND, it is not either up to the task, but it is at least free from the undesired effects that theories that depend on ad hoc postulates will have if these happen to be counterfactual. A well-founded physical theory of the observed phenomena is still pending, but the presented phenomenological analysis and the suggestions made may show the way towards such a theory, and it is hoped that they will inspire efforts in this direction.

ACKNOWLEDGEMENTS

I wish to thank the Scientific Editor of MNRAS and an anonymous reviewer called in by Ap&SS for valuable points of view on previous versions of this paper; to the first especially for having brought me to simplify the evaluation of SNe Ia data, and to the second especially for having identified several points where a misunderstanding could arise.

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