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TIME DILATION IN THE SUPERNOVA LIGHT CURVE AND THE VARIABLE MASS HYPOTHESIS

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ABSTRACT

The recently reported time dilation effect in Type Ia supernova SN 1995K has been claimed to rule out the static universe model of Narlikar & Arp. It is shown here that the variable mass hypothesis which accounts for the redshift phenomenon in the above static universe model does indeed predict the observed effect and that there is no conflict between the data of Leibundgut et al. and the predictions of this model.

Subject headings: cosmology: observations — galaxies: distances and redshifts — supernovae: general — supernovae: individual (SN 1995K)

1. INTRODUCTION

Leibundgut et al. (1996) have recently reported that in the light curve of a distant Type Ia supernova, the rise and fall of the light intensity is over a longer time span than similar events in nearby supernovae. The supernova SN 1995K examined by them exhibits a spectroscopic redshift of 0.479, thus suggesting that it is present in a spiral galaxy of that redshift. In the expanding universe hypothesis, this time dilation is explained as the apparent increase in the observed timescales of an object of cosmological redshift z by the factor $(1 + z)$. These authors remark: "In a static universe, time dilation is not expected to act on the light curve. Redshift in this case is caused by tired light or an equivalent theory (e.g., the variable mass hypothesis ...)." We show here that this statement is not correct so far as the variable mass hypothesis is concerned. In fact, we will demonstrate that the Narlikar-Arp model makes the same prediction as the expanding universe model. In the end, we will stress those observations that would indeed distinguish between the two models.

2. THE VARIABLE MASS HYPOTHESIS

We begin with a summary of the theoretical basis of the model discussed by Narlikar & Arp (1993, hereafter Paper I). The gravitational theory underlying the model is conformally invariant and incorporates Mach's principle in the following way. The inertial mass of a typical particle is determined by the scalar field contributions from the rest of the particles in the universe. The scalar interaction is conformally invariant in the sense that if the measured inertia of a particle in a given spacetime metric g_{ik} is m, then in a conformal transform $\Omega^2 g_{ik}$ of this metric the mass will be m/Ω. For detailed mathematics of this theory see Paper I and the references cited therein.

The resulting gravitational theory is wider in scope than general relativity and is conformally invariant. One can also show that, within this framework, the standard physics on which all astronomical observations are based is also conformally invariant at both the classical and the quantum level.

The outcome of this formulation is that one can look at the standard expanding universe models in a different conformal frame and *still expect to see the same physical phenomena*. Since the Robertson-Walker models used in standard cosmology are conformally flat, one can use a flat spacetime model to describe the same cosmology. Thus one can use a static Minkowski spacetime to describe the same phenomena commonly associated with the expanding universe. The difference is that, whereas in the expanding model the particle masses are constant, in the static model they increase with epoch.

How does the redshift arise in this cosmology? As explained in Paper I, it cannot arise as the result of passage of light through spacetime as it does in the expanding universe. Instead it arises because the particle masses were smaller at the source than they are at the receiver, since the source is being observed at an earlier epoch. Atomic physics then tells us that the wavelengths of standard spectral lines, being reciprocal to the masses, were longer at the source than at the receiver. Hence the redshift is given by

$$1 + z = \frac{m_{\text{receiver}}}{m_{\text{source}}} . \tag{1}$$

The redshift-magnitude relation in this cosmology therefore depends not on any expansion factor but on how the way the inertial mass depends on the epoch t. The simplest solution described in Paper I had

$$m(t) = t^2 . \tag{2}$$

It was shown there that the transformation of this model to the conformal frame in which particle masses are epoch independent leads to the standard $k = 1$ Friedmann model, also commonly known as the Einstein–de Sitter model. The epoch $t = 0$, when the particle masses all vanished in the static model, corresponds in standard cosmology to the singular beginning of the universe.

Thus this cosmology is observationally indistinguishable from the standard Friedmann cosmology if one sticks to tests like Hubble's law, source counts, angular size–redshift relation, surface brightness test, etc. The supernova light-curve test also falls in this class, as we shall now see.

3. APPLICATION TO SUPERNOVA PHYSICS

We now consider the observations of supernovae at large redshifts. In the static model with the variable mass hypothesis, a supernova at redshift $z > 0$ will be made of particles of masses lower than those in a currently observed local supernova, by a factor $(1 + z)^{-1}$. This mass difference applies to all subatomic particles and therefore all dynamical and atomic timescales will be scaled up by this factor. It is generally accepted that the light curves of Type I supernovae result from

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the formation of ^{56}Ni, which decays to ^{56}Co and then into ^{56}Fe. Since these decay times run on the slower clock times of lower mass atoms, they are time dilated by exactly the $(1 + z)$ factor derived either from the more general Narlikar-Arp or the special case Friedmann solution for the general relativistic field equations.

Any differences in the radiation transfer in the expanding gas of lower mass particles would lead to, in first order, zero-point delays. Remaining differences would be masked in the variation of decay rates which is observed in Type I supernovae. For example, there have been factors of 3–5 in energy and considerably different decay rates observed. (Turatto et al. 1996; see also Goldhaber et al. 1997).

This is the reason why we expect the timescale associated with the light curve to be scaled up by this factor. Hence the result observed by Leibundgut et al. (1996) is fully consistent with this model, as it is with any expanding universe model. The interpretation of time dilation is different in the two cases. In the standard cosmology this is due to the expansion of space, whereas in the static model it is due to the slower timescales associated with smaller masses of younger particles.

4. CONCLUDING REMARKS

The difference between the two models comes into focus when one is describing anomalous redshifts. The essential new feature in this cosmology that distinguishes it from the standard one is the possibility that in it new matter may be created in explosive events at $t = t_1 > 0$. The new matter would have zero particle masses at this later epoch t_1, and these masses would subsequently grow as $(t - t_1)^2$. Such matter will therefore be made of particles with masses systematically lower than particles which had their zero-mass epoch at $t = 0$. Thus a quasar ejected from a galaxy and remaining in its neighborhood will have a redshift higher than that of the parent galaxy. This theory therefore provides a natural explanation for the phenomena of anomalous redshifts, without in any way conflicting with the standard phenomena associated with the expanding universe models. We will not go into details of this aspect, which has already been highlighted in Paper I.

One could, however, ask whether matter ejected in supernovae has also been created very recently and therefore carries anomalous redshifts. If this were the case, supernova-related redshifts would not show a tight Hubble relation. The evidence at low redshifts does show a good Hubble relation, and accordingly the supernova matter does not carry anomalous redshifts. The origin of this matter therefore dates back to $t = 0$, and the explanation given in § 3 will apply. Supernova studies at high redshifts will be of interest in setting limits on the anomalous redshift component.

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