Darkness Intensified – Existence of a Nonlinear Threshold in Redshift-Induced Dimming

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Redshift obeys adiabatic invariance. From this fact it follows that not only the individual photons are dimmed by a factor of $z+1$ (if z is the redshift in percent), but the photon flux is reduced by the same factor once more. Hence the luminosity of any source is in the presence of redshift dimmed by a factor of $(z+1)^2$. This model-independent result possibly "explains away" the excess dimming of strongly redshifted Type-Ia supernovae, discovered in 1998.

Why is the night sky so black even in the "deep field" of the Hubble space telescope? An explanation was recently found when a new type of "standard candles" was introduced into measuring astronomy. A white dwarf fed by in-falling material accreted from a close-by companion implodes at a fixed critical mass, displaying a rather standardized time-dependent energy output and spectrum in the process [1]. These high-energy events can be detected and monitored even in the most distant (most redshifted) galaxies. In the last two years, two independent international teams discovered an "excess dimming" of some 25 percent for the most distant Type-Ia supernovae (as these candles are called) [2, 3]. This remarkable finding was hailed the "breakthrough of the year" by "Science" Magazine [4].

The discovery is currently interpreted as implying an "excess distance" of the most highly redshifted objects. That is, the linear Hubble law (redshift as a function of distance) appears "blunted" since the most redshifted objects are plotted much farther away than linearity (and linear expansion) predicts. An "accelerated expansion", and an accompanying "revival of the cosmological constant", are the currently accepted major corollaries [2, 3]. In view of the importance of the discovery and the consequences entailed by it [4], it is perhaps allowed to point out a simple fact which may have gone unnoticed before.

A threshold-like increase of dimming as a function of redshift is a straightforward implication of the principle of action conservation of Hamiltonian mechanics and quantum mechanics. The phenomenon belongs into the range of phenomena collectively known under the name "adiabatic invariance": Any sufficiently slow ("adiabatic") change of a parameter leaves the action invariant [5].

Take a flickering candle (the flickering need not be chaotic) as a case in point. Assume the candle to be observed from a collection of receding spaceships that have just passed overhead, with a different velocity each but all at the same momentary distance to the candle when making their measurement. The recession speed is the parameter varied. Then, with ν_0 and ν_{f0} the frequency of the photons and of the flickering at the candle, and $\nu_r=\nu_0/(1+z)$ and $\nu_f=\nu_{f0}/(1+z)$ those at the observer, the measured intensity of the light results, in addition to the dimming due to the distance of the candle, from a dimming by a factor

$$D_z = \frac{\nu_0}{\nu_r}\,\frac{\nu_{f0}}{\nu_f} = (1+z)^2;\, z>0\,. \tag{1}$$

Note that (1) is a "model-independent" law in the sense of Kolb and Turner [6].

The obvious question which poses itself at this point is: Has (1) been taken into account in the evaluation of the measured brightness data of distant (high-z) Type-Ia supernovae? The observed "excess dimming" [2, 3] clearly is in qualitative agreement with the "accelerated dimming" predicted by (1). Quantitatively, three possibilities exist:

A) The hypothesis that (1) has *not* been taken into explicit account in the evaluation of the data, is false. If so, the "blunted Hubble law" is there to stay with us, with all its revolutionary consequences.

B) The empirical data turn out to match (1) perfectly. If so, the linear Hubble law is resurrected "with a vengeance" (namely, with unprecedented accuracy).

C) The empirical data are "overcorrected" by (1), so that in place of an excess dimming, an "excess brightening" is implicit in the data. If so, a "steepened-up Hubble law" comes into being, with all implications.

Has (1) been taken into account in the evaluation of the empirical data up till now? The answer appears to be in the negative. See, for example, the linear relation between dimness (left-hand ordinate) and luminosity distance (right-hand ordinate) used on the most complete plot of data currently available: Figure 5 of [3]. A theoretical reason why that strategy may have been used invariably up till now can also be indicated: The luminosity distance (d_L) depends on the cosmological model assumed. In the Robertson-Walker metric, for example, it

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depends on the two cosmological parameters $R(t_0)$ and r_1, apart from z (see [6], p. 41, Eq. 2.43); compare also the related, more complicated equations, (1) with footnote 14 of [2] and (2) of [3], in this context. Hence there is no a priori reason apparent at first sight why one should not use *both* the measured luminosity ("d_L") *and* the measured redshift (z) to try and determine the unknown parameters in which one is interested. It is only when the notion of a "model-independent" evaluation of the data [6] comes into view that the dangerousness, not to say falsity, of this way of proceeding becomes apparent [8]. If this interpretation is correct, possibility A) above can be said to have been ruled out already, so that only possibilities B) and C) would remain.

To conclude, a phenomenon on the most majestic scale has been linked to the notion of adiabatic invariance – of microscopic fame. The shape of Hubble's law is at stake once again. Three flowers of differently bent or cocked necks gracefully await their pick. It almost looks as if one of the two more cocked ones were to win the race. What is already certain, however, is that the velvet sky is much darker than anticipated in its deepest pockets which contain the most precious twinkling diamonds – like high-z Type-Ia supernovae.

For J.O.R.

Comment of a Colleague

The relation $l = L/4\pi\,(1+z)^2\,r^2$ between the observable flux density l, the luminosity L, the red shift z and the corrected luminosity distance r was established in 1935 (H. P. Robertson, ApJ **82,** 284). The relation $i_o = i_s/(1+z)^4$ between surface brightness (= bolometric intensity) at the observer, i_o, and at the source, i_s, was found in 1935 by E. P. Hubble and R. C. Tolman (ApJ **82,** 302), its application became known as the Tolman test. For historical comments and remarks about applications see, e.g., J. Peebles, Principles of Physical Cosmology, Princeton University Press 1993, especially pages 91–92. Ever since these and related laws were established, have they been used routinely in evaluating extragalactic observation. These relations are well-known and derived and explained in textbooks.

Response of the Author

There are two versions of the "Tolman test" (thanks for the term!): The model-independent Tolman test and the model-dependent one. It appears that the latter was erroneously applied in the papers in question ([2], [3] and [7] of the above "Note"), in place of the required model-independent version.

As mentioned in the Note, the Robertson-Walker model makes certain predictions as to the dependence of the luminosity distance d_L on redshift z (as well as on time and other cosmological parameters). These relations were used in the quoted papers – as a model-dependent Tolman test, so to speak. But its use is inappropriate. For if there exists a fixed coupling between redshift and dimming because the same object appears dimmed when redshifted, insertion of the two features in an uncoupled manner into a model equation is counterproductive. For it turns a hard (1-dimensional) constraint into a dilute 2-dimensional one.

The dimming has to be redshift-corrected *before* the measured magnitude is inserted into the magnitude-redshift diagram. The commentator fails to provide evidence that this has been done. It will be interesting to see how the two experimental groups will respond.

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[8] See again [6]. The same authors, by the way, already gave an equation very similar to (1), on p. 44 last line of [6], yet with an exponent of –4 rather than –2. One possible explanation of the discrepancy could be a misprint, inherited from an equation used in the derivation of the law. (An equation a few lines up on the same page, $d_A = d_L(1+z)^{-2}$, which should have a –1 rather than –2 in the exponent, qualifies as a potential candidate.) Note that the resulting "amended law", if it indeed exists, would have been derived in the context of the Robertson-Walker metric and hence would be less "model-independent" than (1) which is metric-invariant.

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