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A NEW COSMOLOGICAL MODEL: RED-SHIFT AND SCALE FACTORS

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ABSTRACT

A new cosmological model is considered which doesn't require dark energy. The expansion of the universe is reinterpreted as a 'rescaling' whereby the whole universe can change scale, yet appear static. Rescaling is a symmetry whereby there is a simultaneous change of every length in the universe and all physical constants which contain length dimensions.

It is shown that this interpretation of expansion of the universe, can lead to a Hubble law, due to changing of Hubble constant with time. Also an interpretation of expansion of the universe by red-shift of light, due to a changing of Plancks constant with time. This results in a new relationship between scale factor of the universe and red-shift. The misunderstanding of the true relationship is the cause of the apparent dark energy phenomenon.

In this paper we have discussed about the angular size of the distance that subtend at our location. Also we have discussed about the apparent brightness is related to the luminosity of the galaxy and its distance from us in the expanding universe described by the Robertson-Walker space-time and A related result is the variation of apparent surface brightness with red-shift. Finally it includes the predictions for the magnitudes of supernovae against red-shift are made and found to be in good agreement with supernovae data, without dark energy.

KEYWORDS: Cosmology, Hubble Law, Red-Shift, Distance Scale, Luminosity Distance, Dark Energy

1. INTRODUCTION

On large scales the Universe in homogeneous and isotropic, at least to a good approximation. This means that the Universe does not possess any privileged positions or directions. This idea is of such importance in cosmology that it has been elevated to the status of a Principle, and is usually known as the *Cosmological Principle*. We shall discuss the observational evidence for it later.

There are various approaches one can take to this principle. One is philosophical, and is characterized by the work of Milne in the 1930s and later by Bondi & Gold and Hoyle in 1948. This line of reasoning is based, to a large extent, on the aesthetic appeal of the cosmological principle. Ultimately this appeal stems from the fact that it would indeed be very difficult for us to understand the Universe if physical conditions, or even the laws of physics themselves, were to very dramatically from place to place. These thoughts have been further leading to the *Perfect Cosmological Principle* in which the Universe is the same not only in all places and in all directions, but also at all times. This stronger version of the cosmological principle was formulated by Bondi & Gold (1948) **[23,24]** and it subsequently led Hoyle (1948) and Hoyle & Narlikar (1968, 1964) to develop the *Steady State* Cosmology. This theory implies, amongst other things, the continuous creation of matter to keep the density of the expanding Universe constant.

The Steady State universe was abandoned in the 1960s because of the properties of the cosmic microwave background, radio sources and the cosmological helium abundance which are more readily explained in a Big Bang model than in a Steady State. Nowadays the latter is only of historical interest.

Inflation was introduced in 1981 (Guth 1981), to explain observations that the universe is near critical density. There is, however, no understanding of why it began or ended, or of the nature of the underlying cause of inflation. Due to the observations of distant supernovae (Riess et al 2007), and WMAP measurements of the Cosmic Microwave Background Radiation (Komatsu et al, 2008), cosmologists have concluded that there exists ‘dark energy’, the nature of which is poorly understood. There is a lack of an understanding of a physical mechanism, by which dark energy causes an accelerating expansion of the universe. It is found that the two concepts above are unnecessary if there is an alternative interpretation of the expansion of the universe – a continuous, simultaneous and global changing of all length scales, and all physical constants, which is undetectable to us.

2. THE RESCALING SYMMETRY PRINCIPLE AND ITS CONSEQUENCES

2.1 The Rescaling Symmetry Principle

According to the rescaling symmetry principle, every length in the universe may increase or decrease with almost no noticeable effect to the inhabitants, (figure 1). This continuous and ongoing change in length scale must happen to every length in the whole universe simultaneously, including the size of people, atoms and distances between all objects. Every physical constant must vary too, with the change depending on the number of length dimensions in the quantity.

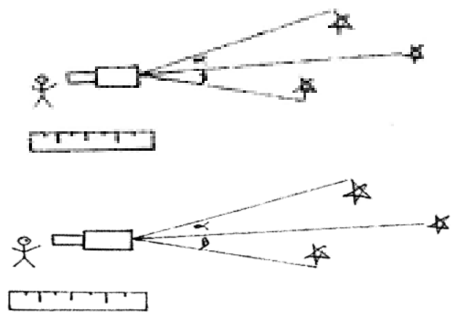

Figure 1: Sketch to Show a Rescaling Universe

A common cosmological time (t) is assumed.

Quantities then rescale according to

$$\frac{dQ}{Q} = nHdt \qquad (1)$$

where ‘n’ is the number of length dimensions in quantity Q. H is the rescaling constant, which is half of Hubble’s constant H_0

$$Q = Q_0 \exp(nHt) \qquad (2)$$

Table 1: The Value of ‘n’ for Various Physical Quantities

Quantity	n
All lengths	1
Speed of light	1
Plancks constant	2
Particle masses	0
Permittivity of free space	-3
Fine structure constant	0
Gravitation constant	3
Hubbles constant	0
Forces	1
Quantity with n length dimensions	n

There has been no convincing evidence for the change of any physical constant with time, although there have been various proposals starting with Dirac's hypothesis of a varying G, (Dirac, 1937). With this proposal the changes would not be measurable. The symmetry principle requires that any local experiment, to measure the change of any physical quantity, in a rescaling universe, would yield a null result. This is due to other relevant quantities rescaling too. For example if an attempt were made to measure the change in the speed of light by timing the passage of a light beam over a given distance, since both the distance and the speed of light rescale in proportion the time of passage would remain the same.

Lunar Laser Ranging has restricted changes in the value of G to 1 part in 10 billion per year. Local measurements would not reveal any change in G with time, due to the symmetry principle. Measurements using distant sources, would also not reveal a change in G with time. An attempt could be made by measuring the velocity of rotation (with Doppler shift) and radius of rotation, of a system similar to the earth-sun system, but many light years away. We would decide (due to the speed of light rescaling too) that the velocity is the same as for the solar system. The radius too would appear the same (e.g. the time of light to cross the orbit would be unchanged) and we would conclude that G was the same in both cases.

The model is consistent with observations that there is no significant change in the fine structure constant with time (Murphy et al. 2001), as it is dimensionless. The rescaling symmetry principle applies to the whole universe simultaneously. It seems as though the universe could be regarded as static, with no change of any physical quantity. However because a rescaling universe is one that is larger now than it used to be, there are some observational differences between the static and rescaling universe cases. These arise from the conservation of energy, as described below.

2.2 The Hubble Law

The proper distance, $\boldsymbol{d_{pr}}$, of a point P from another point $\boldsymbol{P}_0$, which we take to define the origin of a set of polar coordinates $\boldsymbol{r}, \upsilon$, and φ is the distance measured by a chain of rulers held by observers which connect $\boldsymbol{P}$ to $\boldsymbol{P}_0$ at time $\boldsymbol{t}$. From the Robertson-Walker metric with $\boldsymbol{dt} = 0$ this can be seen to be.

$$d_{pr} = \int_0^1 \frac{adr'}{\left(1 - Kr'^2\right)^{1/2}} = af(r) \tag{1}$$

where the function $\boldsymbol{f(r)}$ is respectively

$$f(r) = \sin^{-1} r \left(K = 1\right) \tag{2}$$

$$f(r) = r \quad \left(K = 0\right) \tag{3}$$

$$f(r) = \sinh^{-1} r \left(K = -1\right) \tag{4}$$

Of course this proper distance is of little operational significance because one can never measure simultaneously all the distance elements separating P to P_0. The proper distance at time t is related to that at the present time t_0 by

$$d_{pr}(t_0) = a_0 f(r) = \frac{a_0}{a} d_{pr}(t) \tag{5}$$

where a_0 is the value of a at t_0. Instead of the commoving coordinate r one could also define a radial commoving coordinate of P by the quantity.

$$d_e = a_0 f(r) \tag{6}$$

In this case the relation between commoving coordinates and proper coordinates is just

$$d_c = \frac{a_0}{a} d_{pr} \tag{7}$$

The proper distance d_{pr} of a source may change with time because of the time-dependence of the expansion parameter a. In this case a source at P has a radial velocity with respect to the origin P_0 given by

$$\upsilon_r = af(r) = \frac{a}{a} d_{pr} \tag{8}$$

Equation (2.2.6) is called the *Hubble Law* and the quantity

$$H(t) = \frac{a}{a} \tag{9}$$

Is called the *Hubble constant* or, more accurately, *Hubble parameter* (because it is not constant in time). As we shall see the value of this parameter evaluated at the present time for our Universe, $\boldsymbol{H}(\boldsymbol{t}_0) = \boldsymbol{H}_0$, is known to any great accuracy. It is believed, however, to lie in the interval.

$$40\,km\,\mathrm{sec}^{-1}\,Mpc^{-1} \le H_0 \le 10\,km\,\mathrm{sec}^{-1}\,Mpc^{-1} \tag{10}$$

The unit Mpc^{-1} is defined Mega per sec. It is conventional to take account of the uncertainty in H_0 by defining the dimensionless parameter h to be $\boldsymbol{H}_0 / 100\,\boldsymbol{km}\,\mathrm{sec}^1\,\boldsymbol{Mpc}^{-1}$; The law (8) can, in fact, be derived directly from the cosmological principle if $\upsilon << \boldsymbol{c}$. Consider a triangle defined by the three spatial points $\boldsymbol{O}, \boldsymbol{O'}$ and P. Let the velocity of *P* and $\boldsymbol{O'}$ with respect to O be, respectively, v(r) and v(d). The velocity of P with respect to $\boldsymbol{O'}$ is

$$v'(r') = v(r) - v(d) \tag{11}$$

From the cosmological principle the functions $\boldsymbol{v}$ and $\boldsymbol{v'}$ must be the same.

Therefore

$$v(r-d) = v'(r-d) = v(r) - v(d) \tag{12}$$

Equation (1.4.10) implies a linear relationship between v and r:

$$\upsilon_\alpha = H_\alpha^\beta \, (\alpha, \beta = 1,2,3) \tag{13}$$

If we impose the condition that the velocity field is *rotational.*

$$\nabla \times v = 0 \tag{14}$$

which comes from the condition of isotropy, one can deduce that the matrix $\boldsymbol{H}_\alpha^\beta$ is symmetric and can therefore be diagonalised by an appropriate coordinate transformation. From isotropy, the velocity field must therefore be of the form.

$$\upsilon_i = H\alpha_i \tag{15}$$

where *H* is only a function of time. Equation (15) is simple the Hubble law (8).

Another more simple, way to derive equation (8) is the following. The points OO' and *P* are assumed to be sufficiently close to each other that relativistic space-time curvature effects are negligible. If the universe evolves in a homogeneous and isotropic manner the triangle $OO'P$ must always be similar to by the same factor a/a_0. Consequently the distance between any two points must also be multiplied by the same factor. We therefore have

$$l = \frac{a}{a_0} l_0 \tag{16}$$

where l_0 and l are the lengths of a line segment joining two points at times t_0 and t respectively. From (16) we recover immediately the Hubble law (8).

One property of the Hubble law, which is implicit in the previous reasoning, is that we can treat any spatial position as the origin of a coordinate system.

In fact, referring again to the triangle $OO'P$, we have

$$vP = VO' + V'P = Hd + V'P = Hr \tag{17}$$

and therefore

$$V'P = H(r - d) = Hr' \tag{18}$$

which again in is just the Hubble law, this time expressed about the point O'.

2.3 Red-Shift

It is useful to introduce a new variable related to the expansion parameter *a* which is more directly observable. We call this variable the red-shift *z* and we shall use it extensively from now on in describing the evaluation of the Universe because many of the relevant formulae are very simple when expressed in terms of this variable. We define the red-shift of a luminous source, such as a distant galaxy, by the quantity

$$z = \frac{\lambda_0 - \lambda_e}{\lambda_e} \tag{19}$$

where λ_0 is the wavelength of radiation from the source observed at *O* (which we take to be the origin of our coordinate system) at time t_0 and emitted by the source at some (earlier) time t_e; the source is moving with the expansion of the universe and is at a commoving coordinate *r*. The wavelength of radiation emitted by the source is λ_e. The radiation travels along a light ray (null geodesic) from the source to the observer so that $ds^2 = 0$ and, therefore,

$$\int_{t_e}^{t_0} \frac{cdt}{a} = \int_0^1 \frac{dr}{\left(1 - Kr^2\right)^{1/2}} = f(r) \tag{20}$$

Light emitted from the source at $t_e' = t_e + \delta t_e$ reaches the observer at $t_0' = t_0 + \delta t_0$. Given that $f(r)$ does not change, because r is a commoving coordinate and both the source and the observer are moving with the cosmological expansion, we can write

$$\int_{t'_e}^{t'_0} \frac{cdt}{a} = f(r) \tag{21}$$

If δt and, therefore, δt_0 are small, equation (2.3.2) & (2.3.3) imply that

$$\frac{\delta t_0}{a_0} = \frac{\delta t}{a} \tag{22}$$

If, in particular, $\delta t = 1/\upsilon_e$ and $\delta t_0 = 1/\upsilon_0$ (υ_e and υ_0 are the frequencies of the emitted and observed light, respectively), we will have

$$\upsilon_e a = \upsilon_0 a_0 \tag{23}$$

or, equivalently,

$$\frac{a}{\lambda_e} = \frac{a_0}{\lambda_0} \tag{24}$$

from which

$$1 + z = \frac{a_0}{a} \tag{25}$$

There is also a simply way to recover equation (25), which does not require any knowledge of the metric. Consider two nearby points P and P' participating in the expansion of the Universe. From the Hubble law we have

$$d\upsilon_p = Hdl = \frac{\dot{a}}{a} dl \tag{26}$$

where $d\upsilon_{P'}$ d is the relative velocity of P' with respect to P and dl is the (infinitesimal) distance between P and P'. The point P' sends a light signal at time t and frequency υ which arrives at P with frequency υ' at time $t + dt = t + dl/c$. Since dl is infinitesimal, as is $d\upsilon_{P'}$, we can apply the approximate formula describing the Doppler effect:

$$\frac{\upsilon' - \upsilon}{\upsilon} = \frac{d\upsilon}{\upsilon} \cong -\frac{d\upsilon_{P'}}{c} = -\frac{\dot{a}}{a} \tag{27}$$

The equation (27) integrates immediately to give (23) and therefore (25) A line of reasoning similar to the previous one can be made to recover the evolution of the velocity $\upsilon_p(t)$ of a test particle with respect to a commoving observer. At time $t + dt$ the particle has traveled a distance $dl = \upsilon_p(t)dt$ and thus finds itself moving with respect to a new reference frame which, because of the expansion of the universe, has an expansion velocity $d\upsilon = (a/a)dl$. The velocity of the particle with respect to the new commoving observer is therefore

$$\upsilon_p(t + dt) = \upsilon_p(t) - \frac{\dot{a}}{a} dl = \upsilon_p(t) - \frac{\dot{a}}{a} \upsilon_p(t)dt \tag{28}$$

which, integrated, gives

$$\upsilon_p \alpha\, a^{-1} \tag{29}$$

The results expressed by equations (23) & (29) are a particular example of the fact that, in a universe described by the Robertson-Walker metric, the momentum q of a free particle (whether relativistic or not) scales like $q\,\alpha\, a^{-1}$.

2.4 The Red-Shift versus Distance Relation

In this section we want to extend that analysis to arbitrary values of the red-shift, etc., with the use of the exact solution for zero pressure. Let a light ray emitted at t = t1 from the position r = r1 radically be received at the position r = 0 at time r = t0. Denoting by R1 the value of R at t1, the red-shift z is given as follows:

$$1 + z = R_0 / R_1 \tag{30}$$

We consider the analogue of (3.53) for $k \neq 0$ to get the following equation:

$$\int_0^{r_1} (1 - kr^2)^{-\frac{1}{2}} dr = c \int_{t_1}^{t_0} \frac{dt}{R(t)} = c \int_{R_1}^{R_0} \frac{dR}{RR} \tag{31}$$

We now substitute for R from the exact solution for zero pressure and transform to the integration variable $x = R / R_0$ to get.

$$\int_0^{r_1} (1 - kr^2)^{-\frac{1}{2}} dr = c(R_0 H_0)^{-1} \int_{(1-z)^{-1}}^{1} (1 - 2q_0 + \frac{2q_0}{x})^{-1/2} x^{-1} dx \tag{32}$$

It cab be shown that for all three values of k, the expression for r1 is the same, as follows:

$$r_1 = c\{zq_0 + \frac{(q_0 - 1)\left[-1 + \left(2q_0 z + 1\right)^{\frac{1}{2}}\right]\}}{[H_0 R_0 q_0^2 (1 + z)]}. \tag{33}$$

For large values of the red-shift z it is convenient to define a luminosity distance, measured by comparison of apparent luminosity and absolute luminosity, which are respectively the radiation received by an observer per unit area per unit time from the source, and the radiation emitted by the source per unit solid angle per unit time. The luminosity distance, d_L, is given as follows (see, for example, Weinberg (1972, p. 421):

$$d_L = r_1 R_0^2 / R_1 \tag{34}$$

With the use of (30) and (33), this can be written as follows:

$$d_L = R_0 r_1 (1 + z) = c(H_0 q_0^2)^{-1} \{zq_0 - 1)[-1 + (2q_0 z + 1)^{\frac{1}{2}}]\} \tag{35}$$

For small values of z we get

$$d_L = cH_0^{-1} [z + \frac{1}{2}(1 - q_0) z^2] \tag{36}$$

This equation is independent of models and can be derived using kinematics only.

2.5 Apparent Brightness

The red-shift discussed above shows up in the spectrum of a galaxy. The astronomer measures another quantity associated with the galaxy – its apparent brightness. Let us now see how the apparent brightness is related to the luminosity of the galaxy and its distance from us in the expanding universe described by the Robertson-Walker space-time.

Let *L* be the total energy emitted by galaxy G_1 in unit time during the epoch t_1 when light left it in order to reach us in the present epoch t_0. The red-shift z of the galaxy is therefore given by (26). It is now necessary to specify the wavelength range of observation. To fix our ideas, suppose that the intensity distribution of light from G_1 over wavelengths λ is given by the normalized function $I(\lambda)$. Thus

$$dL = LI(\lambda)d\lambda \tag{37}$$

is the energy emitted by G_1 per unit time over the bandwidth $(\lambda, \lambda + d\lambda)$. If, instead of wavelengths, we wanted to use frequencies, the corresponding intensity function $J(v)$ is related to $I(\lambda)$ by

$$cJ(v) = \lambda^2 I(\lambda). \tag{38}$$

Both $J(v)$ and $I(\lambda)$ are used by the astronomer, the choice depending on convenience.

In the case of isotropic emission of light by G_1, by the time its light reaches us it is distributed uniformly across a sphere of coordinate radius r_1 centered on G_1 (see Figure 1 below). What is the proper surface area of this sphere?

In the Robertson-Walker line element, put *t* = constant and also *r* = constant to get

$$ds^2 = -r^2 S^2 (d\theta^2 + \sin^2\theta\, d\phi^2).$$

This is the line element on the surface of a Euclidean sphere of radius *rS*. Hence the answer to the above question is that light from G_1 is distributed over a total surface area of $4\pi r_1^2 S^2(t_0)$ at time t_0. We may occasionally refer to $rS(t_0)$ as the *proper distance* of a source with coordinate *r*, during the epoch t_0. We now need to know how much light is received per unit time by us across unit proper area held perpendicular to the line of sight to G_1, over a bandwidth $(\lambda_0, \lambda_0 + \Delta\lambda_0)$. Denote this quantity by $F(\lambda_0)\Delta\lambda_0$.

None first that, because of the red-shift, the light arriving with wavelengths in the range $(\lambda_0, \lambda_0 + \Delta\lambda_0.$ left G_1 in the wavelength range

$$\left(\frac{\lambda_0}{1+z}, \frac{\lambda_0 + \Delta\lambda_0}{1+z}\right)$$

Now the total amount of energy that leaves G_1 between the epochs t_1 and $t_1 + \Delta t_1$ in the above frequency range is

$$LI\left(\frac{\lambda_0}{1+z}\right)\frac{\Delta\lambda_0}{1+z}\Delta t_1.$$

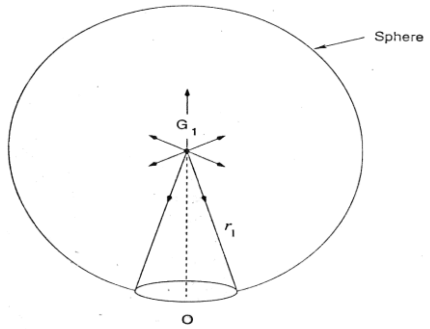

Figure 1: The Radiation Emitted by Galaxy G_1 is Distributed Uniformly across a Sphere of Coordinate Radius r_1 with G_1 as the Centre. The Observer O (that is, Ourselves) Located on this Sphere Would Expect to Receive a Proportionate Quantity of this Radiation across a Unit Area Held Normal to the Direction G_1O

Figure 1 illustrates this effect.

How many photons carry the above quantity of energy? For a small enough bandwidth, we may assume that a typical photon had, at emission, the wavelength $\lambda_0/(1+z)$ a frequency $(1+z)c/\lambda_0$ and hence an energy equal to $(1+z)ch/\lambda_0$, where *h* is Planck's constant. Therefore the required number of photons is

$$\delta N = LI\left(\frac{\lambda_0}{1+z}\right)\frac{\Delta\lambda_0}{1+z}\frac{\Delta t_1}{(1+z)ch/\lambda_0}$$

$$= \frac{L\lambda_0}{ch}\frac{1}{(1+z)^2}I\left(\frac{\lambda_0}{1+z}\right)\Delta\lambda_0\,\Delta t_1.$$

During the epoch of reception, these photons are distributed across a surface area of $4\pi r_1^2 S^2(t_0)$ and are received over a time interval $(t_0, t_0+\Delta t_0)$. Thus the number of photons received by us per unit area held normal to the line of sight and per unit time is given by

$$\frac{L\lambda_0}{ch}\frac{1}{(1+z)^2}I\left(\frac{\lambda_0}{1+z}\right)\Delta\lambda_0\frac{\Delta t_1}{\Delta t_0 4\pi r_1^2 S^2(t_0)}.$$

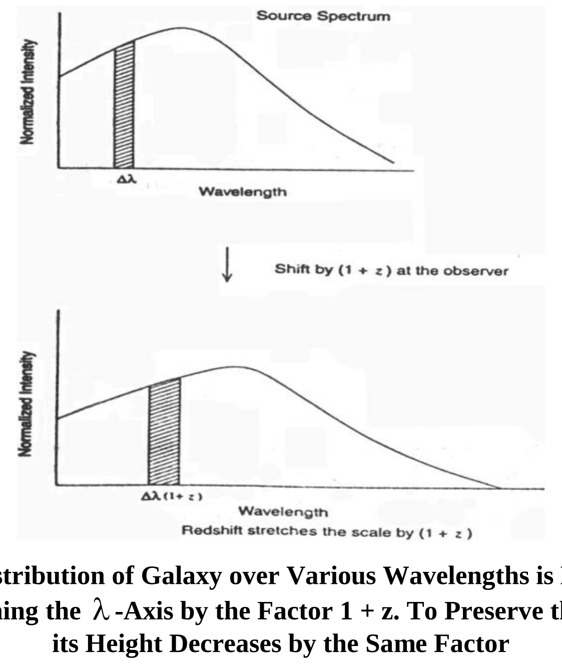

Figure 2: The Intensity Distribution of Galaxy over Various Wavelengths is Modified by the Red-Shift. The Effect is Like Stretching the λ-Axis by the Factor 1 + z. To Preserve the Area under the Curve, its Height Decreases by the Same Factor

During this epoch, because of a scaling down of its frequency by red-shifting, each photon has been degraded in energy by the factor $(1 + z)^{-1}$. Thus each photon now has the energy ch/λ_0. If we multiply the above expression by this factor, we get the quantity we were after:

$$F(\lambda_0)\Delta\lambda_0 = L\frac{1}{(1+z)^2}\frac{\Delta t_1}{\Delta t_0}I\left(\frac{\lambda_0}{1+z}\right)\frac{1}{4\pi r_1^2 S^2(t_0)}\Delta\lambda_0.$$

However, we know that $\Delta t_1/\Delta t_0$ gives us another factor $(1+z)^{-1}$ in the denominator. Thus finally we get

$$F(\lambda_0) = \frac{LI(\lambda_0/1+z)}{(1+z)^3 4\pi r_1^2 S^2(t_0)} \tag{39}$$

In terms of frequencies the result is quoted as the *flux density*

$$S(v_0) = \frac{LJ[V_0(1+z)]}{(1+z)4\pi r_1^2 S^2(t_0)} \tag{40}$$

Here $S(v_0)\Delta v_0$ is the amount of radiation received perpendicular to unit area in unit time across a frequency range $(v_0, v_0 + \Delta v_0)$.

The optical astronomer uses this result in the form (39), while the radio-astronomer uses it in the form (40). The X-ray astronomer uses energies instead of frequencies, so that (40) is scaled by *h*. We will have occasion to use these expressions when we look at the various observational tests of cosmology. We will end this section by deriving a few results of interest to optical astronomy.

The expression (39) integrated over all wavelengths gives

$$F_{bol} = \frac{L_{bol}}{4\pi r_1^2 S^2(t_0)(1+z)^2}, \tag{41}$$

where L_{bol} (=L) is the absolute *bolometric* luminosity of G_1. F_{bol} is correspondingly the apparent bolometric luminosity of G_1. On the logarithmic scale of magnitudes familiar to the optical astronomer, (3.57) becomes

$$m_{bol} = -2.5\log(F_{bol}/F_0),$$

$$M_{bol} = -2.5\log(L_{bol}/L_\Theta) + 4.75,$$

$$m_{bol} - M_{bol} = 5\log D_L - 5, \tag{42}$$

where

$$F_0 = 2.48\times10^{-5}\, erg\, cm^{-2}\, s^{-1},$$

$$L_\Theta = \text{solar luminosity} = 2\times10^{33} erg\, s^{-1}$$

$$D_L = r_1 S(t_0)(1+z). \tag{43}$$

D_1 is called the *luminosity distance* of G_1. If we are interested in a magnitude defined for a particular waveband around λ_0 say, we may similarly use (39) in the logarithmic from with the apparent magnitude defined by

$$m(\lambda_0) = -2.5 \log F(\lambda_0) + \text{constant}$$

The constant depending on the filter used to select that waveband. It is customary to indicate the filter by a suffix attached to *m*. Thus m_{pg} stands for photographic magnitude, m_v for blue magnitude and so on.

Note, however, that, because of the red-shift, the astronomer has to apply a correction to include the effect of the term $I(\lambda_0 / 1+z)$. Thus an astronomer using a red filter may be actually receiving the photons that originated in the blue part of the spectrum of G_1 if $z \approx 1$. This correction, which is crucial to many cosmological observations, is called the *K correction*.

2.6 The Supernovae data

The distance modulus is

$$\mu = 25 + 1\log d_L \tag{44}$$

Using (43) in (44), there is a good match to the supernovae data (Riess 2007), gold set.

3. CONCLUSIONS AND PREDICTIONS

There has been a serious and long-standing misinterpretation of the 'expansion' of the universe, and of the relationship between scale factor of the universe and red-shift. A new cosmology is required in which 'expansion' is replaced with 'rescaling'. The new interpretation predicts an inferred value for omega (matter) of exactly 0.25 (although really 1.0), and supernovae moduli from equations (43) and (44).

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