REDSHIFTS OF UNKNOWN ORIGIN

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1. Introduction

Probably the biggest problem in cosmology is one that many people don't even think about or want to think about. It has to do with the nature of the redshifts of astronomical bodies.

In general, we only acknowledge the existence of three ways of explaining redshifts. These are motions, giving rise through Doppler effect to both blueshifts and redshifts, the expansion of the universe, the explanation normally attributed to Hubble but developed by the leading theoreticians in the period 1927-1930 for the redshifts of galaxies, and gravitational redshifts. In the early 1930s the so-called "tired light" hypothesis was invoked as an alternative to expansion by Zwicky, MacMillan and others to explain the redshifts of galaxies, but it was never accepted though the idea was revived by Max Born and others in the 1950s. There are severe difficulties of a fundamental physical nature in this explanation. Comparatively recently Sandage has demonstrated from the surface brightness test that the redshifts of normal galaxies are due predominantly to expansion and not to tired light.

Why then do I consider that the nature of the redshifts is a major problem. It is because, in my view, there is abundant observational evidence that not all of the redshifts of astronomical objects can be explained by expansion, by Doppler effects, or by gravitation.

In general, the shifts due to different physical processes are additive. Let us suppose that the measured redshift of an object is made up of three terms, a term due to the kinetic motions of stars or galaxies $z_r = v_r/c$, a

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term due to the cosmological expansion z_c, and a term of unknown origin, z_u. For all extended objects (galaxies) the gravitational redshift cz_g must be very small and even for stars, it amounts to no more than $\sim 1-2km\ sec^{-1}$.

The observed redshift z_o is related to the other quantities by the expression

$$(1+z_o) \quad = \quad (1+z_r)(1+z_c)(1+z_g)(1+z_u). \qquad (1)$$

For stars and nebulae in our own galaxy $z_c = 0$, and the highest kinetic velocities measured are $\lesssim 1000km\ sec$, $z_r \leq 0.003$. Thus $z_o = z_r + z_g + z_u$. However in hot stars there is evidence that z_u is not zero. Historically this is known as the K term.

2. The K Term

Where is the K term found and how large is it? The K term originally named by Campbell in 1911, is an excess redshift always seen in the spectra of high luminosity (O and B) stars. It amounts to about $10km\ sec^{-1}$ or $z_u = 0.00003$. While it is very small, the value is well determined, and it is highly significant at the 10 σ level (cf Trümpler 1956). The standard textbooks of the 1930s (cf Russell Dugan & Steward 1938) and distinguished astronomers such as Otto Struve and others all believed the K term to be real. Initially it was thought that it could be explained as a gravitational redshift, but it soon became clear that the gravitational redshift at the surface of a hot star cannot be more than 1-2 $km\ sec^{-1}$ or $z_g \leq 0.000003$. Thus we have a small but measurable redshift term which is *real* but *unexplained*. In a recent study Arp (1992) has extended the earlier work of Trümpler to the A & B supergiants in $h + \chi$ Persei and other young associations, and by using the very accurate redshifts from the $21cm$ line he has been able to detect the same effect in the most luminous stars in the Magellanic Clouds and in other nearby galaxies.

Arp has also made the very important point that there is a great deal of evidence that the hot stars have strong stellar winds. If this is taken into account the intrinsic redshift term must be equal to the algebraic sum of the observed value of z_u and cv_s where v is the stellar wind velocity at the level at which the lines are formed. Thus the true value of z_u must be considerably in excess of 0.00003, and may be as large as 0.0001.

As we shall show, the pattern of investigation common in astronomy is to ignore a result when it cannot be understood theoretically . In the case of the K term the first explanation was that it was a gravitational redshift. When it was clear that this would not work, it was ignored. *But it remains.* At least in this case many reputable scientists remained aware that there was a problem. In contrast nowadays when a phenomenon cannot be understood, there is not only an attempt made to ignore it, but also to suppress studies of it, and treat very harshly those who persist in working in the field.

3. The Tifft Effect

Starting in 1974, Tifft (1974, 1976) claimed that ordinary galaxies show quantized differential redshifts with a period $c\Delta z_u = 70 - 75 km\ sec^{-1}$. He first found this effect in the differences between the redshifts of members of the Coma cluster and later in the redshift differences between physical pairs of galaxies (Tifft 1980). Also Holmberg, and later Arp and Sulentic (1985) showed that in small groups of galaxies dominated by a bright galaxy (e.g. the M81 group) the differences are not distributed at random about the redshift of the main galaxy as would be expected if they were due to satellite motions, or even if they were expanding away from the primary galaxy. It turns out that the mean shift with respect to the central galaxy is displaced to the red. The majority, and some cases all of the differences relative to the central galaxy are redshifts. Not only that but the distribution is quantized with $c\Delta z_u \simeq 72.5 km\ sec^{-1}$. The recent work of Tifft and his associates on other samples of galaxies has suggested that the primary value of $c\Delta z_u$ may be 1/2 or 1/3 of the original number, i.e. about $36 km\ sec^{-1}$ or $24 km\ sec^{-1}$. Further analyses have been made by Guthrie & Napier (1988, 1992, 1994) of samples of nearby galaxies which have very accurate redshifts measured using the 21 cm line. Using 89 spiral galaxies with cz in the range $0 - 1000\ km\ sec^{-1}$ whose redshifts were accurately measured ($\sigma \leq 4 km\ sec^{-1}$) Guthrie & Napier (1992) have shown that when the redshifts are corrected for the optimum solar vector ($v_{\odot} = 227.9\ km\ sec^{-1}$, $l = 98.7, b = -2\overset{\circ}{.}8$) a periodicity is found at $37.22\ km\ sec^{-1}$, with a probability of finding this period by chance of 2.7×10^{-5}. Guthrie & Napier (1994) have extended this result to more galaxies within the supercluster out to $cz = 2600\ km\ sec^{-1}$ and have confirmed the result. Thus the Tifft effect is confirmed in a variety of nearby samples of normal galaxies.

It is very important to stress that the result of such high significance as that attained above is only obtained after the correction for our motion with respect to the Galactic Center i.e. the periodicity found with $c\Delta z_u = 37.2 km\ sec^{-1}$ is associated with the difference in redshifts between the center of mass of our galaxy and the other systems.

4. Large Anomalous Redshifts in Normal Galaxies

There is evidence that individual galaxies can have redshifts very different from their companions, by amounts of the same order as the cosmological redshifts. Such galaxies are rare. Otherwise we would not find a good Hubble relation. The evidence is confined to values of $cz_u \overset{\sim}{<} 10000\ km\ sec^{-1}$ or values of $z_u \overset{\sim}{<} 0.03$. For such galaxies $(1 + z_0) = (1 + z_c)(1 + z_r)(1 + z_u)$ If we suppose that $z_r \ll z_c$, and $z_c \sim z_u$, then $z_u = z_0 - z_c - z_u z_c$ The evidence for this effect comes from pairs, or compact groups of galaxies, which because of their proximity or obvious luminous connections, can be assumed to be at the same distance. Thus, for example, in the case of a physical pair, if the galaxies have grossly different redshifts, the redshift difference at least must have a non-cosmological origin. It is possible in such a case that the anomalous component is due to high kinetic velocity, i.e. it is possible to suppose that the galaxy is literally exploding away from the group, so that $z_u = z_r$, but we do not know whether or not this is the case.

The strongest evidence for this type of phenomenon comes from the compact groups of galaxies. By compact we mean isolated groups of 4-7 members with separations comparable to their diameters and low density surroundings. Three groups were the focus of discussion prior to 1985. They were Stefan's Quintet, Seyferts sextet, and VV116. Each of them contains one galaxy with a redshift very different from the means of the others. In the early 1980s a reasonably complete search for compact groups was carried out by HicksonHickson (1982). He found 100 such groups in the Palomar Sky Survey. Of these, 28 have one or more galaxies with a highly discrepant redshift with respect to the mean of the others. Most of the discussion of the compact groups has been centered about how these can exist, since based on the redshift dispersion among the members (excluding the galaxy with a discrepant redshift) the average time for mergers or expansion is only about $10^{-2}H_0^{-1} \sim 10^8$ years. However, the more important question is whether or not it is reasonable to argue that 28% of the groups should contain a discrepant redshift by accident. After the first three cases were discovered, strenuous attempts were made to argue that the discrepant galaxies were either foreground or background galaxies (cf. discussion of paper by Burbidge & Sargent 1970) but it was very clear from that discussion and in a badly flawed paper by Rose (1977), that from the early days there has been an extreme prejudice involved in the discussion in the sense that the "authorities" are always trying to find a way to explain the apparent associations as accidental. This even happened when analyses were done of the frequency of discrepant redshifts in the Hickson groups. Here the argument is clear-cut. Sulentic has done an extensive analysis. He has counted galaxies in circles with radii 0.5° and 1° about the compact groups (Sulentic 1987; see also Rood & Williams 1989; Kindl 1990) and used the local galaxy density to estimate the number of interlopers expected in each case. For the entire catalog of 100 groups he expects 6, and this is to be compared with the 28 found (Sulentic 1987). Thus he concluded and we concur that this is a highly significant result.

It was to be expected that attempts would be made to square the circle. This has been attempted by Hickson et al. (1988) who carried out a similar investigation to that of Sulentic but they concluded that the numbers expected by chance and actually seen were compatible. How did they manage this. By choosing a search radius which represented the *maximum* radius where an interloper would pass the selection criteria. Despite the fact that there are <u>no</u> compact groups in the catalog out at this larger radius this increases the area involved by a factor of about 250 over that used by Sulentic, and thus reduces the significance of the result. However even with this highly conservative approach the internally discordant redshifts cases can be used with the Sulentic search area, and there are 15 (out of 28) of these to be compared with the 6 expected.

All of the 28 cases are listed in Table 1. It is of some interest that of the 28, 20 have z_u positive and 8 have z_u negative. A remarkable feature seen of Table 1 is that most all of the galaxies with discrepant z are spirals, though the Hickson groups contain the normal mix of elliptical and spirals.

Apart from the compact groups of apparently normal galaxies there are also a small number of galaxies which have been discovered by Arp (1971, 1980) to have companions physically connected to them with very different values of z. The best example is NGC 7603 and its companion joined by a luminous bridge with values of cz of 8000 and $16000 km\ sec^{-1}$ respectively. The other cases are not as convincing, but we must accept that the NGC 7603 pair is direct evidence for a value of $cz_u \sim 10000\ km\ sec^{-1}$. This, together with the discrepant cases in the compact groups suggest that in rare cases apparently normal galaxies can have $cz_u \lesssim |10000| km\ sec^{-1}$.

TABLE 1. Compact Groups with at Least One Discrepant Redshift

Hickson Group No.	Type of Discrepant Galaxy	Group cz_c ($km\ sec^{-1}$)	z_c	$c(z_d - z_c)$ ($km\ sec^{-1}$)	$cz_u = \frac{c(z_d - z_c}{1+z_c}$ ($km\ sec^{-1}$)
2	SBb	4320	0.0144	+17020	+16780
3	Sd	7650	0.0255	+3195	+3800
4	Sab	8400	0.0280	+10080	+9800
5	Sc	12300	0.0410	-4085	-3920
14	Sd	5490	0.0183	+2926	+2870
18	SOa	4175	0.0139	+5844	+5760
20	SOa	1420	0.0484	-3959	-3780
23	Sm	4830	0.0161	+5320	+5240
28	Sdm	11400	0.0380	+18805	+18120
29	CI	31410	0.1047	-18082	-16370
31	Sdm	4110	0.0137	+22790	+22480
38	SBa	8760	0.0292	+15522	+15080
43	Sc	9900	0.0330	+9605	+9300
52	Sdm	12900	0.0430	-6607	-6330
53	Sc	6180	0.0206	+2890	+2830
55	Sc	15780	0.0526	+21100	+20040
59	Scd	4056	0.0135	+15600	+15390
61	Im	3900	0.0130	-2773	-2740
63	SBbc	9330	0.0311	-4102	-3980
64	Sd	10800	0.0360	-4653	-4490
71	SO	9030	0.0301	+11560	+11220
72	Scd	12630	0.0421	+11420	+10960
78	SO	9380	0.0313	+8820	+8550
79	EO	4350	0.0145	+15459	+15240
84	EO	16680	0.0556	+15820	+14990
92	Sd	6450	0.0215	-5664	-5540
93	Sa	5040	0.0168	+3841	+3780
98	Sc	7980	0.0266	+6970	+6300

5. Periodicity in z in Faint Galaxy Surveys

Deep pencil beam surveys of galaxies show periodic redshift effects. The discoverers of this effect do not describe it in this way but they say that galaxies mapped in two or three dimensions are not distributed randomly, but show an excess correlation and apparent regularity in the galaxy distribution with a characteristic scale of $128h^{-1}Mpc$ for $z \geq 0.2$ (Broadhurst, et al. 1990; Broadhurst 1994). This corresponds to $cz_u = 12800km\ sec^{-1}$ or $z_u = 0.0426$ for $H_o = 50km\ sec^{-1}Mpc^{-1}$.

6. Summary of Results on Normal Stars and Galaxies

So far we have shown that there is evidence for the existence of an unexplained redshift component in ordinary stars and galaxies ranging from very small values in stars, to periodic differential effects in galaxies, larger components in discrepant systems and even larger periodicity with $z_u \simeq 0.043$.

None of these except possibly the last, is in conflict with the idea that the largest part of the redshift has a cosmological origin for most galaxies. It may have only a minor effect on the tightness of the Hubble relation. However understanding it may help us with the larger problem. One important effect may be that when we compute the random motions of galaxies in clusters and groups by taking each redshift away from the mean, part of the apparent random motion term may be due to a non-zero value of Δz_u. If this is true, the kinetic energy of the group may be over estimated. Thus the virial mass will be over-estimated. This in turn means that the dark matter present which is usually determined by using the virial theorem may be over-estimated.

7. Redshift of other Extragalactic Objects

We now turn to the evidence for an unexplained redshift term in the spectrum of extragalactic objects which are not simply composed of stars and hot gas. These are nearly all of the extragalactic objects which are called strong emission line radio galaxies, active galactic nuclei (AGN) and QSOs. It is in some of these objects that z_u may dominate and periodicities in z_u may also exist. Some may contain stars but in almost all cases the redshifts are measured from lines emitted by hot gas.

From the time of the original discovery of the QSOs it was clear that they did not follow a tight Hubble relation. As more and more objects were discovered it became clear that the Hubble diagram has largely the appearance of a scatter diagram (cf Hewitt & Burbidge 1993 Fig 1 for a recent demonstration of this). The conventional interpretation is that they show a very large scatter in their intrinsic luminosities.

8. Individual Redshifts of QSOs

The strongest evidence that a large part of z_0 for QSOs is of unknown origin is the clear association of many bright QSOs with comparatively nearby bright galaxies. Early work by Arp (1966, 1967 summarized by Arp 1987) and a detailed statistical study of the association of 3C QSOs with the Shapley Ames galaxies (Burbidge et al. 1971) showed that there are far more QSO-galaxy pairs with small separations than are expected by chance. For these systems z_g is very small, so that we must suppose that $z_Q \simeq z_u$. Many statistical studies have been made, and for bright galaxies and bright QSOs this result has been obtained many times. Apart from the pair NGC 4319 - Mk 205 where a clear luminous bridge joins the two objects (Sulentic & Arp 1987) the evidence is generally statistical, and is confined to the brightest QSOs ($\overset{\sim}{<}$ 18^m) and galaxies brighter than $m = 15.5$. The surface density of QSOs on the sky is well established. Thus this evidence of physical association of QSOs with $z_0 \overset{\sim}{<} 2$ and galaxies with separations $\leq 3'$ is very strong at a level of at least 6σ (Burbidge 1979, 1980, Burbidge et al. 1990). There are now six of seven pairs where the morphology involving gas contours and other features as well as the statistics indicates that both components of the pair lie at the same distance (Burbidge 1994). Many still dispute the statistical evidence, but an unbiased analysis suggests that it is acceptable. The argument that the redshifts are due to gravitational lensing of background QSOs in the halos of the galaxies made originally by Canizares (1980) fails because there are not enough faint QSOs to be amplified by objects in the halos of galaxies (Ostriker 1990, Arp 1990).

These results directly imply that z_u can have large values at least up to $z \simeq 2$. At the same time there is evidence that some QSOs have associated faint galaxies with almost identical redshifts so that for some QSOs $z_u \approx 0$.

9. Periodicity in the redshifts of QSOs and Related Objects

Early in the studies of QSOs and related objects a sharp peak at $z = 1.955$ was reported (Burbidge & Burbidge 1967). Soon after this it was noticed that if we restrict ourselves to QSOs, and related objects distinguished from normal galaxies by their non-thermal continuum and emission line spectra which are similar to those of QSOs, the redshifts show a quantized appearance at values $z_u = n \times 0.061$ at least up to $n \simeq 10$. Since the redshifts are mostly very small compared with those of the QSOs most of the objects in the original survey (70 objects) were those in the second category. In this distribution a strong peak was seen at $z = 0.061$ and at multiples of it (Burbidge 1968).

As more QSO redshifts were obtained several additional peaks in the redshift distribution became apparent, particularly at $z = 0.30$, 0.60, 0.96 and 1.41 (Burbidge, 1978). Karlsson (1977) showed that these peaks are periodic with $\Delta \log(1+z) = 0.089$ i.e. the ratio of successive peaks $(1 + z_0^{n+1})/(1 + z_u^n) = 1.227$. The first peak is at $z_u = 0.061$ and the last discernable peak at $z_u = 1.955$. This analysis referenced above was based upon about 600 QSO redshifts which are mostly comparatively bright radio QSOs. This result was confirmed using larger samples by Fang et al. (1982) and Depaquit, Pecker and Vigier (1985).

A new catalog of extragalactic emission line objects similar to QSOs was compiled recently by Hewitt and Burbidge (1991). It contains 935 objects. More than 700 have redshifts $z \leq 0.2$ and most are Seyfert galaxies, though many emission-line radio galaxies are included with $z \geq 0.2$. A histogram of these redshifts shows a large peak at $z = 0.06$ (Burbidge & Hewitt (1990). There are 89 objects out of about 500 with $z_u < 0.2$, in the very narrow redshift interval $\Delta z = 0.01$ between $z = 0.055$ and $z = 0.065$. Duari, DasGupta and Narlikar (1992) did a new analysis based on all the QSOs which have not been identified by any technique which determines to some extent the redshift range of the objects being discovered. This meant that they used 2146 objects out of the catalogs which contain more than 8000 objects (Hewitt and Burbidge 1991, 1993).

In a plot in their paper the peaks at 0.06, 0.18, 0.24, 0.30, 0.32, 0.36, 0.40, 0.47, 0.55 and 0.62 can easily be seen. Duari et al. did a power spectrum analysis similar to that done originally on an earlier sample by Burbidge & O'Dell (1972) who confirmed the original peaks at 0.06 and 1.955. They also carried out the Kolmogoroff-Smirnoff test and the comb-tooth test and found strong evidence for the periodicity at 0.06 (the exact value is 0.0565, and its significance is increased when the redshifts are transformed to the Galactocentric frame). A second period of 0.0128 was also found at high significance. As far as the periodicity in large scale in $\Delta \log(1+z)$ is concerned they were more cautious, and the reality of this periodicity has been recently questioned by Scott (1990).

To summarize these investigations, it appears that the peak at 0.06 and the periodicity up to about $n = 10$ which was first noted in 1968 has been shown to exist with something like 30 times as much data as existed then. The peak at 1.955 is also well established, and the larger scale periodicity may still need more study.

In discussing the reality of such effects it should always be borne in mind that if Δz_u is real and periodic quite a small range of values of z_c will be very effective in smearing out the peaks which would arise from the z_u term. Thus to find peaks at all in the observed data at multiples of 0.06 or at other values is remarkable. It strongly suggests that the cosmological components of objects in these redshift ranges must be very small ($z_c \ll 0.01$), or that

z_c and z_u are related.

10. Summary

We have shown that there is very good observational evidence for the existence in nature of a redshift component of unknown origin in stars, galaxies and QSOs. We summarize the evidence in Table 2.

TABLE 2.

TYPE OF	z_u	$cz_u(km\ sec^{-1})$	Comments
High Luminosity Stars	~ 0.00003	~ 10	K term observed
High Luminosity Stars	~ 0.0001	~ 30	K term corrected for stellar wind velocity
Normal Galaxies	$n_{\times}0.000125$	$n_{\times}37.6(\pm 0.2)$	Tifft effect - Guthrie and Napier
Normal Galaxies (rare)	$\sim \pm 0.03$	$\sim \pm 10000$	Discrepant redshifts in compact groups and pairs
Faint Galaxies $z \leq 0.2$	$n_{\times}0.043$	$n_{\times}12800$	Pencil beam studies of faint galaxies
QSOs	$\sim 0 - 2.5$		Non-cosmological redshifts based on QSO-galaxy associations
QSOs & AGN	$n_{\times}0.06$	$\sim n_{\times}18000$	In Seyfert galaxies, QSOs, and radio galaxies
QSOs and AGN	0.06, 0.30, 0.60 0.96, 1.41, 1.95		Peaks in redshift distribution

The repercussions on cosmology of this general result may be very considerable. When the values of $|u_r|$ are small it may be possible to treat them as minor perturbations on the cosmological redshifts expected in one's favorite cosmological model. But for the objects with the largest redshifts, the QSOs and the radio galaxies, it may very well be that for this class of objects at least only a small part of the observed redshift is cosmological in origin. Alternatively it may be that the large values of z_u found are rare among QSOs (it is only well established for the brighter QSOs) so that a large part of conventional cosmology will survive.

In any case we should take these phenomena seriously and try to understand them rather than ignoring them.

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