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The mystery of redshift periodicities

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Abstract

This paper briefly reviews the different data sets of extragalactic objects including nearby and distant galaxies and quasars that show statistically significant peaks at periodic intervals of redshifts. At present the data are not complete in any sense but they are substantial enough to make us worry about the fundamental assumption that the universe is homogeneous on a large scale. Moreover, evidence of this kind has not only persisted in spite of rigorous statistical analysis but has grown with time so that it cannot be altogether ignored.

Key words: Extragalactic astronomy, cosmology.

1. Introduction

In this communication, we briefly review some peculiar patterns emerging from the distribution of redshifts of extragalactic objects. To set the stage, let us first define the redshift and its conventional interpretation.

When the astronomer obtains the spectrum of an extragalactic object he finds the spectral lines in it shifted towards the red end, *i.e.*, the lines appear at wavelengths longer than their standard laboratory values. Typically, if a line has a wavelength $\lambda = \lambda_0 + \delta\lambda$ where λ_0 is its standard laboratory wavelength, then

$$z = \frac{\delta\lambda}{\lambda_0} \tag{1}$$

is defined as the redshift.

In the early days (1920s), when the spectra of nearby galaxies showed redshifts, they were interpreted as the consequence of Doppler effect. With cosmological models based on Einstein's general relativity gaining currency in the 1930s, the phenomenon came to be interpreted differently: in terms of an expanding universe. According to this interpretation, a scale factor S sets the overall linear size of the universe at any given time t. As t increases S also increases so that all cosmic separations proportionately increase.

Now consider the following situation. Light from a distant galaxy leaves at time t_1 reaching us here at time t_0. The scale factor has increased between t_1 and t_0 by the factor

$$1 + z = \frac{S(t_0)}{S(t_1)} . \tag{2}$$

It can be shown that this z is none other than the redshift of formula (1).

It is clear that if $S(t)$ is a monotonically increasing function then the farther the galaxy is the larger the interval $t_0 - t_1$ and the larger is the redshift. For small redshifts ($z \ll 1$) the effect is linear with distance

$$z = \frac{H_0}{c} D \tag{3}$$

where c is the speed of light and H_0, Hubble's constant, named after Edwin P. Hubble who first found the linear law in 1929 from observations of nearby galaxies[1]. Within the present range of observational uncertainty, $H_0^{-1} = 9{\cdot}8 h_0^{-1} \times 10^9$ years, with $0{\cdot}5 \leqslant h_0 \leqslant 1$.

We further expect, under the cosmological interpretation of z, that the extragalactic objects being distributed homogeneously on a large enough scale, the z-distribution will be a continuous one. However, over the last 2–3 decades data have been coming in that become hard to reconcile with the above expectation. Here, we will describe three different types of populations which show these anomalous features.

2. Pencil beam surveys of galaxies

In an attempt to look for large-scale correlations in the distribution of galaxies, Broadhurst *et al*[2] in 1990 combined data from four distinct surveys at the north and south galactic poles to produce a well-sampled distribution of galaxies by redshift. The surveys extended up to distances of $\sim 6 \times 10^9\ h_0^{-1}$ light years. They found that the galaxies appear to have clumped distributions at distances that are multiples of $\sim 420 \times 10^6 h_0^{-1}$ light years. That is, if we interpret the redshifts of the observed galaxies, they are distributed nonrandomly, more in a cellular fashion. It should be noted that this work is confined to pencil beam surveys, *i.e.*, to surveys covering a small angular area in the given direction.

The survey of Broadhurst *et al* is the first one of its kind, and one may legitimately reserve judgement until more such pencil beam surveys are performed in different directions. For, any one beam covers a small solid angle and does not give us a feel for the global large-scale structure.

It has been argued by Neta Bahcall that if one looks at the global large-scale structure at a nearby distance one finds clumping of galaxies on different scales ranging from clusters of 3–30 $\times 10^9$ light years to superclusters of 150–300 $\times 10^9$ light years in linear size[3]. A pencil beam cutting across discrete structures of the latter type could very well reveal a nonrandom distribution along its direction, with gaps of the right order: for, the superclusters are distributed in filamentary structures separated by giant voids. Thus, if one looked in different directions one may find a less-striking effect with different characteristic separations.

Some indications of another survey do show this tendency. However, it is still mysterious that the Broadhurst *et al* survey should find a periodicity to distances much farther out than could be accounted for by the local distribution of superclusters.

3. The Tifft effect

In the mid-1970s, Tifft[4] reported a curious result, *viz.*, a small-scale periodicity amounting to 72 km s^{-1} in cz in redshifts of galaxies in cluster. That is, the redshifts were not smoothly distributed but seemed to come in 'bands' with the above separation. To make the result credible it was necessary, however, to reduce the experimental errors of measurements of cz from the then existing magnitude of ~ 25 km s^{-1} to much lower values. Tifft and Cocke[5] used the 21-cm measurements of high quality as they became subsequently available and were able to claim in 1983 that the effect was still there with errors reduced to $|\Delta cz| < 9$ km s^{-1}.

In 1985, Arp and Sulentic[6] found the effect to several multiples of 72 km s^{-1} for a sample of 260 galaxies in more than 80 groups. The accuracy of the sample ranged from $|\Delta cz| < 8$ km s^{-1} to $|\Delta cz| < 4$ km s^{-1}. In a typical situation there is a large galaxy and a small companion with the latter having an excess redshift very close to an integral multiple of 72 km s^{-1}. In more recent years, the Tifft effect is found in a wider classes of situations.

The analyses of the above data have been subjected to rigorous statistical scrutinee by Guthrie and Napier who started off as being sceptics of the whole idea. Was the sample subject to selection effects? Did the observational accuracy warrant the conclusion? Above all, what confidence can be attached to the claimed periodicity?

Guthrie and Napier have more recently considered an independent sample of 89 nearby spiral galaxies[7]. Power spectrum analysis of heliocentric redshifts corrected for solar motion round the galactic centre gave an underlying periodicity of 37·2 km s^{-1} at a high confidence level, *i.e.*, at nearly half the Tifft value of ~ 72 km s^{-1}. The probability of the observed peak at this value arising from chance is in the range 3×10^{-6} to 3×10^{-4}.

4. Peaks and periodicities in the distributions of quasar redshifts

The quasi-stellar objects (QSOs or quasars in brief) are extragalactic objects with large redshifts, the largest one known so far being $\sim 4{\cdot}9$. Unlike galaxies, the quasar spectra have absorption lines also. The first two quasars, 3C48 and 3C273, were discovered in 1963 and their number has steadily grown to around 5000 by now. If we plot the histogram of all redshifts we should expect to see a more or less continuous distribution, with no peaks or periodicities.

Instead, what is found is a histogram with sharp peaks and troughs and one can see at a glance that the distribution is far from smooth. The peaks appear at z-values roughly at multiples of 0·06. Is this effect real? Is it significant? Does it arise from some covert selection effect? Will it go away as the quasar sample grows?

On the last count the answer is not very reassuring if one goes by the history of the subject. The effect was first noticed by Burbidge[8] in 1968 when the quasar sample was very small, numbering to only 70. In a recent analysis, Duari *et al*[9] have used a sample of 2164 quasars. They still find the effect. We will first consider this work.

The latest catalogue of quasars by Burbidge and Hewitt (1990: private communication) contains 4282 emission line redshifts of quasars of which 2118 have their redshifts measured by the grism technique while the rest, 2164, have more accurate redshift determination by other spectroscopic methods. In the above work, we used the latter group of quasars. (The grism technique picks out quasars in a somewhat select redshift range and may therefore be subject to selection effects).

The above sample was subjected to four different statistical techniques, briefly described below:

(i) *Power spectrum analysis* : Consider the quantity

$$S_N(k) = \left|\sum_{n=1}^{N} e^{-ikz_n}\right|^2 \tag{3}$$

where $(z_1, \ldots z_N)$ is the redshift sample. If there is an underlying periodicity we expect $S_N(k)$ to have a large value for the corresponding k value. Thus, if we see a peak at a value k_0 we should suspect a period $2\pi/k_0$ in the z-distribution. Statistical theory will tell us what confidence level to attach to a given peak. The power spectrum analysis shows two peaks of $S_N(k)$ above the 90 per cent confidence level. One at 90·21 per cent corresponds to a period $\Delta z = 0{\cdot}0565$ while the other at 98·28 per cent corresponds to $\Delta z = 0{\cdot}0129$.

(ii) *The Generalized Rayleigh Test*: This test has been used previously by gamma-ray astronomers and it helps find the period more accurately (including its harmonics) if we know it (or suspect it) approximately. The test applies to a parameter

$$Z_p^2 = \frac{2}{N}\sum_{r=1}^{p}\left[\left(\sum_{n=1}^{N}\cos 2\pi r\varphi_n\right)^2 + \left(\sum_{n=1}^{N}\sin 2\pi r\varphi_m\right)^2\right] \tag{4}$$

where p is an integer and $\xi\phi_n$ is the remainder when $z_n - z_1$ is divided by ξ, the assumed trial periodicity.

Now, if the data do not have periodicity, Z_p^2 behaves like χ^2 with $2p$ degrees of freedom. If we find that Z_p^2 is very large, then we suspect periodicity. For the above data, we find that both Z_1^2 and Z_2^2 are maximum when $\xi = 0{\cdot}0565$ with the probability of exceeding these values by chance, less than 0·01. Thus, we again find that 0·0565 is a likely periodicity with a confidence level exceeding 99 per cent. For $\xi = 0{\cdot}0127$ and $\xi = 0{\cdot}0121$ we similarly find maximum Z_1^2 and Z_2^2, respectively, although their confidence levels are somewhat lower at, respectively, 98 and 95 per cent.

iii) *The Kolmogorov–Smirnov Test* : Here we can first examine the distribution round an individual peak to see whether the peak is nonrandom, and then we can look at all peaks taken together. Thus for the rth peak in the histogram, we consider the redshift intervals of the peak as well as those immediately preceding and following it. If the redshifts in these three ranges are $z_1, z_2, \ldots, z_R$, then we compare this distribution with a uniform distribution of R objects in the range $[z_1, z_R]$. This comparison is made with the K-S test.

We find that the K-S test does not pronounce any individual peak as nonrandom. It does, however, make the entire collection of peaks highly nonrandom with a probability $\leqslant 10^{-4}$ of coming about by chance.

(iv) *The comb-tooth template Test* : In this test, we 'create' a comb-like distribution with the following function:

$$c(z, z_0) = \begin{cases} 1 \text{ for } z_0 + n\xi - \dfrac{\omega}{2} < z < z_0 + n\xi + \dfrac{\omega}{2}, \ n = 1, 2, \ldots \\ 0 \qquad \text{otherwise,} \end{cases} \tag{5}$$

with $\omega < \xi$.

The parameters of the comb are z_0 where it starts, the gap (or period) between the successive teeth ξ, and the width of a tooth ω. We define the correlation function with the actual distribution $(z_1, \ldots z_N)$ by

$$r(z_0) = \sum_{n=1}^{N} c(z_n, z_0). \tag{6}$$

Clearly, if the actual distribution has an underlying periodicity we can spot it by 'moving the comb' across the distribution and by adjusting ξ and ω. It turns out that the correlation shoots up when the comb periodicity is $\Delta z = 0{\cdot}0565$ and the starting point is at $z_0 = 0{\cdot}0035$. Thus the first peak is at 0·06.

It is worth noting that the power spectrum test shows that the two periodicities are stable with respect to the transformation of all redshifts to galactocentric coordinates. The confidence level in fact marginally increases. Further, Monte Carlo simulations of unpeaked parent distributions do not as a rule produce such periodicities.

5. Conclusion

At this stage it is wiser to leave these results at their face value, rather than begin to look for their theoretical significance. It is likely that they contain some germ of truth—some information about the large-scale structure of the universe—that our theoretical models have not yet incorporated. It would, however, be unwise to ignore this input which in some cases has not only persisted but grown in significance.

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