Crystal Spheres in Velocity Space?

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In a collaborative programme involving Dr. B.N.G. Guthrie and the author at the Royal Observatory, Edinburgh, the claim that extragalactic redshifts are periodic, in the sense described by Tifft, is being subjected to a rigorous statistical scrutiny. The current status of this programme is discussed. First, the methodological approach and the analytical techniques are described. The latter are based on power spectrum analysis and involve extensive Monte Carlo simulations for testing the periodicity hypothesis against various null ones. Second, the result of applying these techniques is described: two samples have so far been examined, namely the Virgo cluster and the nearest field galaxies. The situation is found to be somewhat more complicated than that described by Tifft and coworkers: no redshift periodicity could be detected in irregular dwarf galaxies, nor was any found amongst the galaxies of the Virgo core. However amongst the nearby field galaxies, and the outer spirals of the Virgo cluster, evidence of strong periodicity in the general ranges claimed by Tifft emerged (~ 72 km s^{-1} for cluster galaxies, ~ 36 km s^{-1} for field galaxies). The measured effect is significantly stronger in the more accurate data, the correlation with accuracy being significant at a ~ 99 percent level. Leaving this correlation aside, the probabilities that the Virgo and field galaxy periodicities are due to chance are respectively a few parts in a thousand and a few parts in ten thousand. The phenomenon seems to be related to the motion of the Sun around the Galactic centre rather than, say, its motion with respect to the Local Group or the microwave background.

Introduction

That the redshifts of some extragalactic objects may be caused, not by cosmological expansion or the familiar Doppler effect, but by a phenomenon as yet unknown to current physics, is a long-standing and highly controversial claim in astrophysics. It is probably fair to state that very few astronomers at the present time take the idea seriously, although recently, in the context of 'known physics', a number of non-velocity redshift mechanisms have come to light (Wolf 1987, Cheng *et al*. 1990), and other suggestions are made in this volume, some of them venturing beyond well-established physics.

Whatever the ultimate significance of such mechanisms for real astronomical environments, it does not at the moment seem that they will be able to cope with one particular 'anomalous redshift' claim; this is the assertion that, when corrected for a local solar motion, extragalactic redshifts are periodic, with periodicity ~72 km s^{-1} or simple fractions thereof.

This extraordinary notion, that redshifts exhibit a periodic structure symmetric around the Sun (when corrected for a local solar motion), would seem to be more at home with Aristotle's geocentric crystal spheres than with modern astrophysics. It is hardly surprising, therefore, that it has so far attracted little attention in the astronomical community. However, the hypothesis of periodic redshifts has the advantage of vulnerability: it is eminently falsifiable. There exist standard techniques for recognizing any periodicities which might exist in noisy data, and assigning confidence levels to them. In recent years an abundance of new data have appeared in the form of 21 cm observations of nearby galaxies, the formal errors in the data being often only a few km s^{-1}, substantially less than the periodicities being claimed. Thus the hypothesis of periodic redshifts may be tested against new, accurate data using well-established techniques.

What is required to settle the issue, then, is a straightforward job of data analysis. Specifically, one would like to see: (i) a rigorous, objective period-hunting technique, applied to (ii) new data samples, selected without bias, (iii) these samples comprising accurate and reliable redshifts.

A proper methodological procedure is also required. A given set of data may be examined this way and that, hunches tried out and so on, and from this a strictly specified hypothesis may emerge. A formal confidence level may be derived, but the test really comes when new data are examined to see whether the hypothesis holds (or, is preferred over a null hypothesis). Almost inevitably, if the hypothesis holds up at all at some level, there will be some refinement that would make it fit the new data even better. Is the refinement real or an illusion? The only test is to specify the refined hypothesis and try it out on further new data, and so on, confirmatory and exploratory phases intermingling.

The purely statistical approach, as described above, has its limitations. It may for example be argued that in physics reproducibility is more important than rigorous statistical validation, and that the constant recurrence of a phenomenon in different samples matters more than formal confidence levels; furthermore, the general who acted on information only if it was statistically verifiable at a confidence level ≥ 0.999 would presumably not win many battles!

Thus factors other than statistics are involved in making judgements on a contentious claim (including, it appears, social ones: Kuhn 1962). Nevertheless a strong statistical result, positive or negative, is a formidable weapon in the arsenal, to be ignored at one's peril. Any statistical hypothesis is only a model and like any other model it will eventually fail when confronted with sufficient new data; however the important question in the present situation is whether some new physical phenomenon is being uncovered, not whether its original description, seen through a glass darkly, turns out to be right in every detail.

The Hypothesis

The main results claimed by Tifft and his colleagues (see for example Tifft and Cocke 1984,1989) are:

(a) The redshifts of galaxies in groups and clusters have a periodicity in the range 70 to 75 km s^{-1}; that is, the periodicity is *local* to a given group.

(b) There is a *global* periodicity, for galaxies distributed anywhere over the sky, when a suitable correction for the solar motion is made. This periodicity is ~ 24 kms^{-1} for galaxies with narrow line profiles, and ~ 36 km s^{-1} for those with wide profiles if the same solar motion is adopted. The solar motion for which the periodicities appear is

$$\mathbf{V}_{\mathrm{Sol}} = (233.6 \text{ km s}^{-1}, l_{\mathrm{Sol}} = 98.6°, b_{\mathrm{Sol}} = 0.2°)$$

where $\mathbf{V}_{\mathrm{Sol}}$ represents a solar vector towards galactic longitude l_{Sol} and latitude b_{Sol}. Thus a term $\mathbf{V}_{\mathrm{Sol}} \cos \chi$ has to be subtracted from the heliocentric redshifts before the 'quantization' becomes apparent, χ being the elongation of a galaxy from the solar apex.

These results were largely derived by a binning technique. However such techniques are somewhat inflexible and may lack power. The concept of a 'bin width' has no natural counterpart in the physical situation, and there is always the possibility that the extra freedoms involved in choosing bin width and starting position may introduce bias in subtle ways. In addition, the fact of having to subtract a solar motion introduces a further three adjustable parameters, namely the components of motion; thus, without careful control, spurious solutions might be introduced, with insignificant signals being boosted by adjustment of the solar motion. In the present study two new analytical elements were introduced. In the first place a fresh analytical approach was adopted, namely a power spectrum analysis. There are several versions of *PSA*, which is flexible and well understood theoretically. Secondly, extensive use was made of Monte Carlo simulations to control the freedoms introduced by having a disposable solar motion. The alleged redshift quantization was isolated by generating and operating on synthetic redshift distributions, while freezing every other variable. Thus any significant difference in the *PSA*s of the real as against the synthetic redshifts can only be due to some property of the real redshifts.

The Samples

The two data samples examined so far have been the Virgo cluster, and the nearby field galaxies, that is galaxies with heliocentric redshifts $cz \leq 1000$ km s^{-1}. Given that the data samples should be selected in an unbiased way, these choices would seem to be appropriate, the Virgo cluster for example being simply the nearest rich cluster of galaxies. It is also a happy circumstance that with few exceptions the galaxies in these samples had not been used in previous studies of the phenomenon, and so amount to fresh, independent data. The details can be found in the papers by the author and his colleague (Guthrie and Napier 1990, 1991). The Virgo cluster sample comprises 112 spiral galaxies within 10° of M87, the bright central galaxy of the Virgo cluster, and 77 dwarf irregular galaxies from the same region. A number of sources were culled to obtain the Virgo spiral sample, the criteria being that accurate HI redshifts (better than ± 10 km s^{-1}) with undistorted, symmetric profiles were required. Where several sources were involved a comparison of the overlapping galaxies showed internal agreement to within 4 or 5 km s^{-1}, which encourages one to believe that systematic differences between groups in arriving at a mean redshift are not too important. The dwarf irregular sample was based on an HI survey of galaxies carried out by Hoffman *et al*. (1987) using the Arecibo reflector, and the internal accuracies of these measures appear to be similar to those of the spiral galaxies.

The nearby galaxy sample was taken from a database compiled by Bottinelli *et al*. (1990). The selection procedure was simple: galaxies were chosen if their redshifts had quoted standard errors ≤ 4 km s^{-1}, if they lay outside the region of the Virgo cluster, and if their heliocentric redshifts, when corrected for the Sun's motion with respect to the Local Group, were less than 1000 km s^{-1}. The resulting sample of nearby galaxies comprised 106 spirals and 62 irregulars. Within the spirals of this set were all 48 spirals with $cz \leq 1000$ km s^{-1} adopted as redshift calibrators by Baeisi-Pillastrini and Palumbo (1986). The significance of these calibrators is the extreme accuracy of their measured redshifts; to be included in the BP catalogue, a galaxy was required to have had at least five consistent and independent measurements. As it turns out that the measured strength of a signal is very sensitive to the accuracy of the data, these calibrators provide an independent test on the reality or otherwise of the quantization.

Analytical Techniques

> *...periodicities found by harmonic analysis and not predicted by previous theoretical considerations should be mistrusted, as many complications are capable of giving spurious periods; not more than a tenth of those that have been asserted will bear a proper statistical examination. (Jeffreys and Jeffreys 1962, p. 452).*

Given, then, that extracting periodicities from noisy data is a notoriously treacherous task, and that the physical nature of the alleged phenomenon is not only 'not predicted' but is quite extraordinary, it is clear that a degree of caution may be called for! To facilitate the discussion of technique, a simple, intuitive approach to the problem is described here, in which it is hoped that the complications and pitfalls are made clear.

Consider a time series, or a set of marks laid out on a string. The question is asked: are these marks distributed at random, or is there a periodicity, or whatever? One way to test for a suspected periodicity would be to wrap the string round a drum whose circumference equals the periodicity being examined. If the signals are periodic, then they will reinforce each other, tending to lie in a particular quadrant. If on the other hand the signals are randomly distributed on the string, then one might suppose that they will be randomly spread around the drum. In general however this is not so, a fact which represents the first of the 'many complications'. The reason can be seen in Figure 1; what one finds is that in general there are m wraps around part of the drum, and (m+1) wraps around another. Thus unless the length of the time series is an integer multiple of the period being examined, there will be a concentration of points around some particular segment and

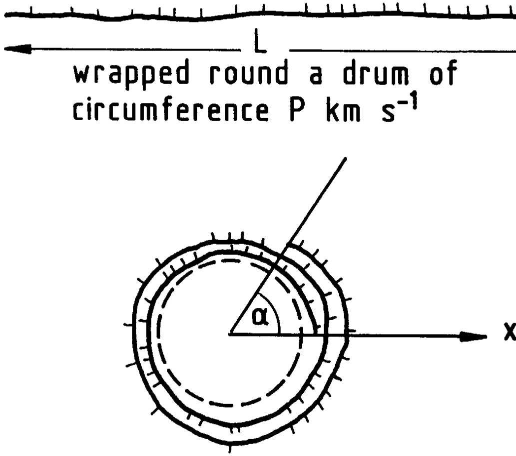


Figure 1 - Conversion of data a from linear (cz_i) to circular. Edge effects manifest themselves as partial wrapping of data over an angle *a*

this, in the hands of the unwary, could spuriously enhance the significance of any apparent periodicity in the data.

In the particular case where the background data are random, independent and uniformly distributed (that is, the noise is ‘white’), this edge effect can be allowed for to sufficient accuracy by weighting the data: those data in the segment with the extra wrap are multiplied by $m/(m+1)$. The effect is shown in Figure 2, where power spectra of synthetic period data are shown with and without the wrapping correction. As will be described, one is essentially, in the power spectrum, varying the circumference of the drum (usually measured by frequency, along the horizontal axis), and employing a measure of the anisotropy of the signals (and hence their strength) along the vertical axis.

The measure employed can be understood if, at a particular frequency (or drum circumference), the signals are represented by

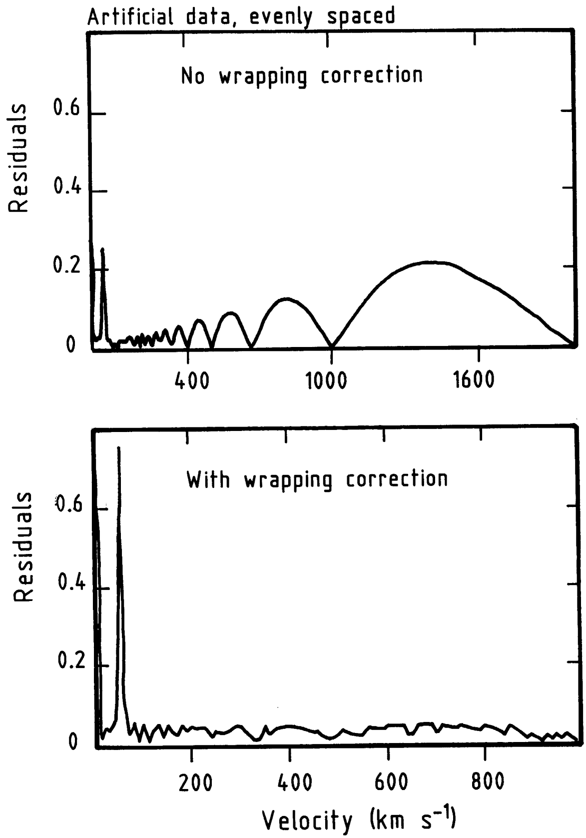
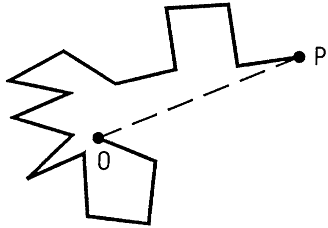
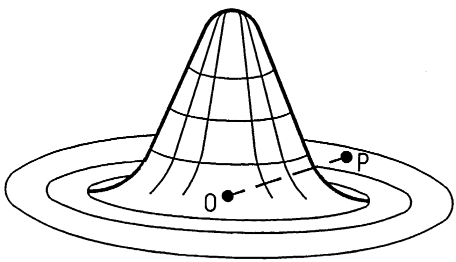


Figure 2 - Power spectra for uniformly spaced synthetic data without (top), and with (bottom), the wrapping correction m/(m+1). In this diagram the quantity R/N is plotted against periodicity (rather than power $2R^2/N$ against frequency).

unit vectors. Then for random and independent data, uniformly scattered over the time series, the sum of the unit vectors describes the outcome of a random walk, provided the wrapping correction has been applied.



a.



b.

Figure 3 - Random walk in two dimensions. For vectors of equal length and random directions, the resultant OP is distributed as a two-dimensional gaussian. By circularly transforming the redshift data (Figure 1) and adding the vectors, the amplitude of a peak OP in a power spectrum can be compared with the known probability distribution for a random walk.

Of course, if there is an appreciable signal, this vector sum will not fit the expected random walk pattern, since the vectors will then have a preferred direction and their sum will lie at an inordinate distance from the origin (Figure 3). Now the probability distribution of the distances for a random walk in two dimensions is known, and so the probability that chance will produce a vector sum of the magnitude observed, or greater, can be found. If R represents the distance from the origin traversed after N random steps each of unit length, in the mean R varies as $(N)^{1/2}$. Defining a 'power' $I = 2R^2/N$, the probability distribution for a random walk is 0.5 exp($-I/2$). The mean value of I is 2, independent of the number of observations.

Even when a significant signal is found to be present, it does not follow that there is a periodicity: 'significance' may only mean a departure from the assumptions of randomness, uniformity and independence of signals. Simple non-uniformities arising from redshift clustering due to physical clustering of galaxies or a tendency to binary nature, or even selection effects such as the tendency for a catalogue to contain many low redshift galaxies, must first be allowed for. Fortunately, these effects are readily incorporated into Monte Carlo simulations, and one can in addition apply simple tests to find whether a power spectrum has the 'white noise' behaviour expected on the simple null hypothesis.

The Analysis

The Virgo Cluster

As it happens, the galaxies of the Virgo cluster are fairly uniformly distributed in redshift, there are few if any binaries or small groups within it, and the redshift range is so wide (~ 2500 km s^{-1}) that edge effects as described above are of little importance when testing for a ~ 72 km s^{-1} periodicity. As a first approach to the question a fixed solar apex was taken, correcting for the Sun's motion relative to the Local Group. This was taken to be $(\mathbf{V}_{\mathrm{Sol}}, l_{\mathrm{Sol}}, b_{\mathrm{Sol}}) = (252$ km s^{-1}, $100°, 0°)$ which is representative of various determinations. Use of different published determinations of this solar motion made only a few km s^{-1} difference to the corrected redshifts.

With this correction to the redshifts, a *PSA* was carried out on the 112 spiral galaxies of the Virgo sample, over the period range 20 to 500 km s^{-1} (Figure 4a). A peak ($I = 10.5$) did appear at 71.25 km s^{-1},

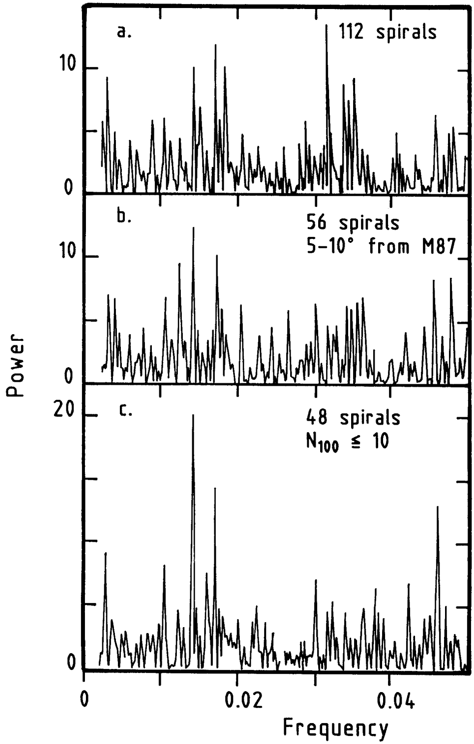


Figure 4 - Power spectra for (a) the whole sample of 112 Virgo spirals, (b) the 56 spiral 5–10° from M87, and (c) the 48 spirals with $N_{100} \leq 10$. Note the progressive enhancement of the peak at P^{-1} ~0.014 ~71.4 kms^{-1} as sub-samples in the low density regions of the cluster are picked out.

that is within the range being tested, but it was only the third highest of several in the range. Depending on whether a few redshift groupings within the cluster were physically real or accidental, the peak could be said to confirm the hypothesis at a modest confidence level, in the range 0.96 to 0.99, with the adopted solar motion. This confidence level may be described as annoying, in that it neither convincingly demonstrates the presence of the phenomenon, nor could one comfortably assert that it demonstrates its absence.

The 112 Virgo spirals were then divided into two groups: those less than 5° from M87, and those 5°-10° from it. This giant elliptical galaxy is close to the centre of the Virgo cluster and the spirals were in effect being divided into those in the core of the cluster, and those beyond. The apparently arbitrary division arose from the fact that, in a preliminary study of binary galaxies (Napier *et al.* 1988), the authors had found evidence for periodicity of redshifts in binary galaxies with accurately determined redshifts, but only if the galaxies were not too close together. There was no rigorous demonstration of this result which had therefore to be seen, in the present study, as an arbitrary 'hunch' rather than a specific prediction.

It was found that the power of the ~72 km s^{-1} signal resided largely in those galaxies which lay beyond the core (Figure 4b). This division into two groups is somewhat rough-and-ready (the Virgo cluster is elongated and irregular, and M87 may well be off-centre), and it was refined by making use of a movable counting circle to determine the number N_{100} of galaxies within 100 minutes of arc of each of the 112 spirals. The radius of the counting circle was taken to be large enough to include a few galaxies, in most cases, but small enough to reflect the projected density of the galaxies. The power spectrum of those galaxies lying in the low density regions of the Virgo cluster, defined by $N_{100} \leq 10$, is shown in Figure 4c; there are now 48 spiral galaxies to be analysed, and their power spectrum is dominated by a strong peak (I=20.4) occurring at 71.1 km s^{-1}. The next step is to ask how significant this peak really is.

Firstly, a number of statistical tests were carried out on the power spectrum away from the peak. No significant departures from a 'white noise' spectrum could be detected, nor were there any detectable bumps or trends. Thus, given also the smallness of edge effects in the sample, it was possible to apply the analytic formulae for random, uniform data, and the question reduced to: given a sample of such data, what is the probability of obtaining a peak $I \geq 20.4$ in the range 70-75 km s^{-1} by chance? This probability turns out to be about one in ten thousand; however, we then had to take account of the fact that the peak was obtained by an *a posteriori* search, that is, the density correlation was not part of the initial hypothesis being tested. Given the freedom of choice in deciding what constitutes a low density region, it turns out that the probability of a chance effect is reduced by a factor of five or ten; and given further the possibility of some slight departure from white noise below the threshold of detectability, the probability that a random distribution of redshifts would throw up a peak of this strength by chance turns out to be one or a few parts in a thousand; the signal may therefore be said to be real at an overall confidence level in the range $0.997 \leq C \leq 0.999$.

This result was obtained by adopting a specific, fixed solar velocity vector. However, since there is at present no understanding of the physical phenomenon, if it exists, it is not immediately clear what solar velocity correction should appropriately be applied. Accordingly, the solar apex was then treated as a free variable. For each assumed apex, a set of corrected redshifts was constructed. A *PSA* was carried out on each set of corrected redshifts, and the value $I_{\max}$ of the highest peak in the range 70–75 km s^{-1} was noted. Thus to each prescribed solar vector $\mathbf{V}_{\mathrm{Sol}}$ a single number $I_{\max}$ could be assigned, measuring the strength of the hypothesized periodicity for that vector. The direction of the solar vector was varied over the whole sky, and various speeds $\mathbf{V}_{\mathrm{Sol}}$ were adopted. This game was played with the 112 spirals with good redshifts in the Virgo cluster, and also with the 48 spirals away from the Virgo core. Whole-sky contour maps of $I_{\max}$ were plotted in which, for a given solar speed,

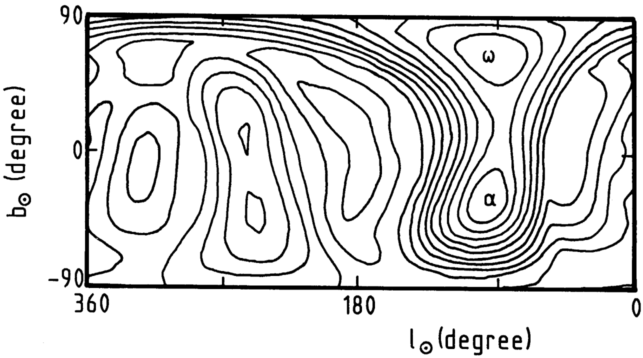


Figure 5 - Contour map of I-values for the 48 spirals with $\mathbf{N}_{100} \leq 10$. For each solar apex (one 'pixel' on the map) a power spectrum analysis of the 48 corrected redshifts was carried out in the period range 70-75 km s^{-1}. The twin peaks *a* and *w* have I~25.8.

the behaviour of I_{max} could be seen as a function of the galactic coordinates of the assumed solar vector.

One such map is shown in Figure 5, for the 48 galaxies. It can be seen that there are twin peaks α and ω, with I_{max}=25.6 and 26.1 respectively. The previously fixed solar apex, at $l_{Sol} = 100°$, $b_{Sol} = 0°$, turns out to lie in the saddle point between the peaks. Once again, the question arises whether a random distribution of galaxy redshifts and celestial positions could produce maps with $I \geq 26$ by chance. To test this, synthetic data were constructed in which the positions of the galaxies on the celestial spheres were preserved, but they were assigned redshifts at random, although with an overall distribution corresponding to that observed. Each set of synthetic data was then processed in an identical manner to that of the real data; thus one whole-sky map was produced for each such data set. The maximum value of I_{max} for each map was recorded and their frequency distribution derived. These synthetic maps yield the result that an I_{max}

value greater than 26 will be obtained by chance about once in a thousand trials. Thus although varying the solar apex yields higher peaks, the extra degrees of freedom involved means that the significance of the result stays about the same.

Similar analyses were carried out on the 77 dwarf irregulars with good redshifts in the Virgo cluster. Both fixed and variable solar vectors were used. No evidence of quantization was found in these small galaxies; the behaviour of the dwarves, in this respect, was strikingly different from that of the spirals.

The upshot of the Virgo study is that the claim of a redshift periodicity in the region of ~72 km s^{-1} is upheld, at a moderately high confidence level. Significant new information is that the phenomenon seems to apply only to the spiral galaxies, and only in the less dense regions of the cluster. In arriving at these conclusions, due allowance has been made for the *a posteriori* nature of the exploratory part of the investigation. The result is not very sensitive to the adopted solar apex; one can only make the imprecise statement that the periodicity emerges if the solar apex is in the general direction and magnitude of that assumed for the solar motion around the Galactic centre. This imprecision is not surprising, given the small angular extent of the Virgo cluster over the celestial sphere. If the phenomenon is real, however, there must at least be consistency with the solar vectors obtained from other samples.

The Nearby Field galaxies

Of the 106 nearby field spirals from the Bottinelli *et al*. sample, eight overlap with the sample of 80 narrow-line field galaxies used by Tifft and Cocke (1984) in their initial determination of the solar vector, and redshift periodicity of ~36 km s^{-1}. Thus, strictly, the remaining 98 galaxies constitute a pristine sample in the sense of not having been used by them in the initial determination of the solar vector and the

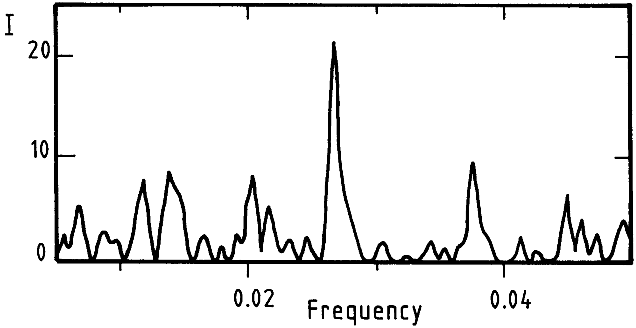


Figure 6 - Power spectrum of the redshifts of 98 nearby spirals corrected for the solar vector derived by Tifft and Cocke (1984). The range of trial frequencies is from 0.005 to 0.050 ($20 \le P \le 200$ km s^{-1}), and the highest peak (I=21.4) is at P=37.2 kms^{-1}.

periodicity, and they may therefore be employed to test the hypothesis. This is done in the present section. However, of the remaining 98, a further nine were used by them to confirm their solar vector and 'discover' another periodicity for the broad line galaxies. To obtain a sample which is entirely independent of the Tifft and Cocke study, these nine should be excluded also, reducing the sample from 106 to 89. The study by Guthrie and Napier (1991) uses these 89. The results obtained are not significantly different for the two samples.

The power spectrum of the 98 galaxies, when the heliocentric redshifts are corrected with the Tifft and Cocke solar vector, is shown in Figure 6. The prominent peak has I=21.4 at a periodicity 37.2 km s^{-1}. With the fixed solar apex, assuming no prior hypothesis and a uniform cz distribution uncomplicated by binaries or clustering, then the peak is real at a confidence level ~0.996. If one is testing the prior hypothesis of redshift periodicity in the range 32-37.5 km s^{-1} (as we are doing), then the peak is significant at C~0.9995. Expressed otherwise, if the redshifts are random, independent and uniform, then the odds on such a strong chance periodicity in this range are two thousand to one against.

The assumptions of the null hypothesis must of course first be tested before this periodicity can be accepted as real. The mean value of the power in a white noise spectrum is 2; that in the observed spectrum away from the peak is 2.22±0.34, not significantly different, while further statistical testing revealed no significant difference between the expected and observed cumulative *I*-distributions. Within the uncertainties, therefore, the data reveal a white noise spectrum.

The standard error 0.34 in the mean power could, however, imply some undetected 'pinkness' in the noise which, if truly present, could reduce the calculated improbabilities by a factor ~3. Any such pinkness, amounting to a departure from the assumptions of the null hypothesis, will arise from spatial or redshift non-uniformities; one could imagine that an uneven distribution of galaxies over the celestial sphere would throw up preferred solar velocity corrections and hence perhaps a tendency towards a preferred redshift range, or more probably, there might be some mild tendency to clustering in the 'field' galaxies, which would yield redshift correlations, manifesting themselves as bumps or wiggles in the power spectrum. A more sensitive test of significance was therefore applied.

Once more, synthetic redshifts were constructed. The positions of the 98 galaxies over the sky were preserved, as was the overall redshift distribution, but now a 'fuzz' was added to the heliocentric redshifts of individual galaxies, a random quantity in the range 0-ΔV $km\ s^{-1}$ being applied to the true redshifts. After each such application, a *PSA* was carried out and the $I_{\max}$ in the relevant range was recorded. Histograms, each comprising 3000 evaluations of $I_{\max}$ were then constructed: the results are shown in Figure 7.

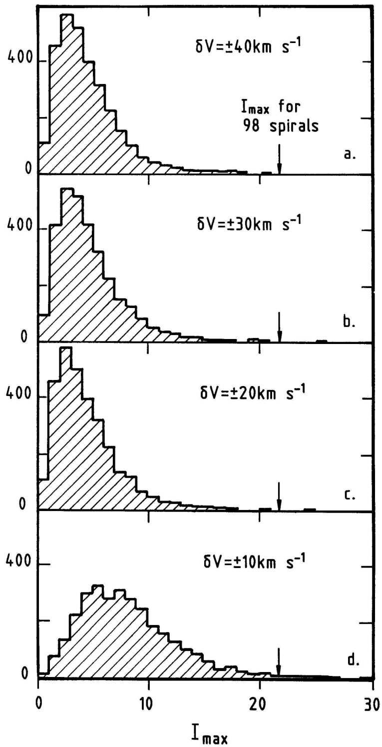


Figure 7 - Distribution of I_{max} in the range 35-37.5 kms^{-1} for power spectra of 3000 sets of 98 synthetic redshifts. Each set of 98 was generated by adding, to each measured redshift in the sample, a random displacement in the range shown. The corresponding I_{max} for the 'real' 98 redshifts is indicated by an arrow in

Everything in the real data has been preserved in the artificial data, with the exception of the precise individual redshifts, which are allowed to vary by a small amount up to ΔV km s^{-1}. Any significant difference between the real and artificial data can therefore only be due to the imposed 'fuzz'. From Figure 7 it can be seen that the peak in the actual redshifts is strongly offset from the general run of the artificial ones. For $\Delta V = 60$ km s^{-1} example, corresponding to a fuzz of ±30 km s^{-1}, I_{max} is found from the trials to be significant at a confidence level ~0.9996. In the limit where ΔV tends to zero, the real and artificial data coincide; the null hypothesis and that under test then become one. Remarkably, however, it can be seen (Figure 7d) that even when the imposed fuzz is as little as 10 km s^{-1} the real and artificial data seem to behave quite differently. These results imply that spatial or velocity correlations do not significantly affect the result; it seems that a strict redshift periodicity, and not, say, a rough episodicity, is required to account for the result. The correlation length of any velocity clustering would have to be less than, say, 10 km s^{-1} for galaxies separated typically by megaparsecs, and we would have to introduce new physics in order to avoid new physics!

An Exploratory Study

Strictly speaking, these results conclude the testing of the redshift periodicity hypothesis to date. Two independent samples have been taken, one the galaxies of the nearest rich cluster, the other the nearest 98 spiral galaxies in the general field with well-determined redshifts. It has been found that the hypothesis of periodicity is a much better fit to the new data than that of randomness. The confidence levels are high, and the phenomenon appears to be a strict periodicity rather than, say, redshift clustering. This is the main result to emerge from the investigation so far.

However, there is no reason to expect that the hypothesis is in its final form; it could happen, for example, that some other solar vector would fit the data even more closely or, as seems much more likely, that there is in fact no unique solar vector over distances of order $cz \sim 1000$ km s^{-1}. The question of a variable solar vector was investigated, as with the Virgo cluster, by constructing maps of I_{max} for various assumed solar speeds, and recording the highest I_{max} to appear anywhere on the map. Since this was now an exploratory rather than confirmatory phase of the investigation, the eight galaxies which overlapped with Tifft's sample were reinstated, making 106 nearby field galaxies in all. The range of solar vectors explored was

$$85° \leq l_{\mathrm{Sol}} \leq 104°$$

$$–° \leq b_{\mathrm{Sol}} \leq 4°$$

$$200 \leq \mathbf{V}_{\mathrm{Sol}} \leq 330 \text{ km s}^{-1}$$

A thousand such maps were constructed, and peak values of $I_{\max}$ in excess of 30 were found for solar vectors given by

$$\mathbf{V}_{\mathrm{Sol}} = 212\text{km s}^{-1},\ l_{\mathrm{Sol}} = 94°,\ b_{\mathrm{Sol}} = -13°$$

and

$$\mathbf{V}_{\mathrm{Sol}} = 228\text{km s}^{-1},\ l_{\mathrm{Sol}} = 98°,\ b_{\mathrm{Sol}} = -3°$$

A comparison with maps constructed from suitable artificial data revealed that such peaks would occur by chance once or twice in ten thousand trials (Figure 8). Whole sky searches over a broader range of $\mathbf{V}_{\mathrm{Sol}}$ revealed no evidence that significant directions were being missed by searching over the limited sky areas above. The second of these peaks is within 6 km s^{-1} and 3° of the position derived by Tifft and Cocke, but there is nothing in the analysis which requires any 'real' vector to coincide with this peak as against the other, or indeed with either.

The periodicity corresponding to these peaks is 37.3 km s^{-1}. This is close to the edge of the range being tested and raises the question of whether the true period may lie beyond the limits which (somewhat arbitrarily) have been set. In fact, tests on artificial data revealed that the difference between 37.3 and the 36.3 km s^{-1} of the Tifft hypothesis is too large to be accounted for by the likely uncertainties in the measured redshifts. However, the assumption made so far, that a unique solar apex exists for all the objects in the sample, is unlikely to be realistic; for example, the mean gravitational vector may swing through ~30° between us and the Virgo cluster. Assuming that the solar apex relevant to the phenomenon behaves similarly, trials on synthetic data revealed that, if a fixed solar apex was assumed nevertheless, the peaks in the power spectra were severely degraded, and the errors introduced in the derived parameters were typically about 1 km s^{-1} in period, 5 km s^{-1} in the derived solar speed, and 10° in the galactic coordinates of the apex.

An extensive set of trials on random data revealed that the ability of the power spectrum technique to detect a signal depends rather critically on the accuracy of the raw data. If a redshift dispersion of more than say 7 or 8 km s^{-1} is imposed on a periodic signal, the peak may sink into the noise. Allowing for slight profile asymmetries, galactic warps and so on, it seems that the accuracies of the corrected signals in the field sample are indeed a critical issue. This sensitivity to error suggests a further test: if the phenomenon is real, the power should reside in the best data; if it is a statistical artefact, the power should not be a function of redshift accuracy.

Accordingly, the sample was divided into the 48 redshift calibrators of extremely high precision, and the 58 non-calibrators. The power was found to reside almost entirely in the calibrators, the difference between the two being significant at the 99 percent level (technical details are to be found in Guthrie and Napier 1991). Taking the 106 nearby field spirals as the database, one may say that there is a probability $\leq 10^{-3}$ that the observed peaks occur by chance, and a further probability $\sim 10^{-2}$ that the power should be concentrated to the extent observed in the more accurately determined redshifts.

A similar exercise revealed that there was a significant difference between narrow and wide profile galaxies, in the sense that the power seemed to reside in the wider profiles, as claimed by Tifft and colleagues. This too had ~99 percent significance.

The degradation of signal arising from the non-uniqueness of the solar velocity vector may be offset to some extent by exploring a reduced volume of circumsolar space. Clearly, in the limit, one runs out of data, but one might hope that, if the phenomenon is real, the

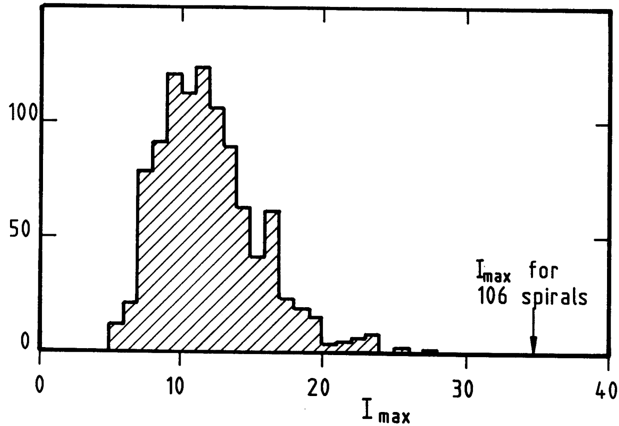


Figure 8 - Distribution of I_{max} from 1000 20°×20° contour maps. Each map represents a search for periodicity, in the range 35-37.5 km s^{-1} in a set of 106 synthetic redshifts, with the solar vector allowed to vary over the range described in the text. Thus each datum represents the highest I-value reached anywhere in a given map. The value I_{max} = 34.6 for the 106 nearby spirals is indicated by an arrow.

signal would maintain its strength in spite of the reducing *N*, simply because of the increasing commonality of the solar vector. To look into this issue more closely, an investigation of the nearest 26 spiral galaxy calibrators (with $cz \leq 600$ km s^{-1}) was carried out. The maps yielded two peaks with I~30 at periods ~39 km s^{-1}. The corresponding solar vectors were

$$212 \text{ km s}^{-1}, 92°, -1°$$

$$242 \text{ km s}^{-1}, 94°, +2°$$

both very close to (90°,0°). This result is consistent with the supposition that, as the volume of space being searched is shrunk, so does the 'best' solar vector collapse towards the direction of Galactic rotation. Comparison with the maps of random galaxy redshifts reveals that the confidence level of the periodicity is maintained (*C*~0.9994) in spite of the sparse number of redshifts now being analyzed.

In spite of an extensive search for periodicities amongst the dwarf irregular galaxies of the field, none has been found. In this respect the situation is the same as that pertaining to the Virgo galaxies.

Conclusions

I have briefly described the current status of an investigation by Dr Guthrie and myself into the question of redshift periodicities. The requirements of any such enquiry are statistical rigour applied to accurately measured, fresh redshift samples, chosen without bias. The main conclusions reached so far are as follows:

No evidence has been found for redshift periodicity in the dwarf irregular galaxies, whether in the Virgo cluster or the general field. Taken as a whole, the Virgo spirals appear to show a redshift periodicity of ~71 km s^{-1}, but the result is somewhat marginal (*C*~0.99). However, a periodicity seems to be present in the less dense regions of the Virgo cluster, the confidence level of this latter result being ~0.999. In the nearby field galaxies, a periodicity of about 37 km s^{-1} seems to be present (*C*~0.9995). Its measured strength resides almost entirely in the galaxies with the most accurately determined redshifts. This latter correlation is real at the 99 percent level and is expected if a real phenomenon is being measured, but not if a statistical artefact is involved. A positive correlation of periodicity with line profile width, claimed by Tifft, is also confirmed, at a similar confidence level. Finally, by exploring smaller volumes of space around the Sun, one finds that the redshift periodicity is maintained, and the solar vector in relation to which it emerges converges towards the known solar motion around the centre of the

Galaxy. The convergence holds to within the measured accuracy of that motion (within a few degrees and a few km s^{-1}).

It might be thought very surprising indeed that the extraordinary claims of periodicity in redshifts have so far survived a rigorous statistical scrutiny of new data. If one adopts a principle of minimum astonishment, then the least that can be said is that the alleged phenomenon has not gone away. Tempting though it is to plunge immediately into theoretical speculation, the first goal of the authors is to extend their statistical analysis to further extragalactic samples.

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