Periodicities of Quasar Redshifts in Large Area Surveys

H. Arp
Max-Planck-Institut für Astrophysik, 85741 Garching, Germany

D. Roscoe
Applied Maths Dept, Sheffield University, Sheffield S37RH, UK

C. Fulton
Centre for Astronomy, James Cook University, Townsville Queensland 4811, Australia.

Abstract

We test the periodicity of quasar redshifts in the 2dF and SDSS surveys. In the overall surveys redshift peaks are already apparent in the brighter quasars. But by analyzing sample areas in detail it is shown that the redshifts fit very exactly the long standing Karlsson formula and confirm the existence of preferred values in the distribution of quasar redshifts.

We introduce a powerful new test for groups of quasars of differing redshifts which not only demonstrates the periodicity of the redshifts, but also their physical association with a parent galaxy. Further such analyses of the large area surveys should produce more information on the properties of the periodicity.

Subject headings galaxies: active – quasars: general

1 Introduction

Hawkins, Maddox and Merrifield (2002) claimed that an analysis of the large 2dF quasar sample showed no evidence for quasar redshift periodicity. The purpose of the present paper is not to address their criticism of past evidence (that has been done by Napier and Burbidge, 2003, who show the past evidence is indeed valid) - but rather to show that, also contrary to the Hawkins et al. claim, a simple qualitative analysis of the new data plus a detailed analysis of a few sample fields, reveals that quasar periodicity is indeed strongly present.

1.1 The Basic Hypothesis

The model which is used here to predict properties of quasars in the survey regions is radically different from the canonical view. It has evolved from observational evidence over the past thirty eight years and has two main properties which can be expressed as:

- Quasars originate from within, and are ejected by, active galaxies. Thus, in a real sense, active galaxies are parents to quasars;

The evidence for this arose originally from radio quasars paired across disturbed galaxies. It was accepted that galaxies ejected radio sources in roughly opposite directions. Ejection therefore appeared a natural explanation for these pairs of radio quasars (Arp 1967). Later X-ray jets were often found in the cores of radio jets and they were in turn associated with the more numerous X-ray quasars in pairs and lines - many of which were found to be aligned with the nuclei of low redshift galaxies.

Some of the papers generally showing evidence involving radio emitting QSOs and bright galaxies, X-ray-emitting QSOs and active galaxies, and pairs with optical, radio and X-ray connections are (Burbidge et al.
1971; Pietsch et al. 1994; Burbidge 1995, 1997, 1999; Radecke 1997; Arp 1967, 1996, 1997, 1999, 2003; Arp et al. 1990, 2002). Two of the most impressive recent examples are the X-ray QSOs connected to the nucleus of NGC 3628 (Arp et al. 2002) and the discovery of two QSOs in the optical bridge between NGC 7603 and its companion galaxy (López-Corredoira and Gutiérrez 2002).

The observed physical association with low redshift galaxies is explained by the ejection hypothesis but it also enables an empirical test of the periodic nature of the quasar redshifts because;

- Quasars are always higher redshift than the ejecting galaxy and none show negative redshifts of approaching velocities. The conclusion is that they must have intrinsic redshifts which are much larger than their ejection velocities. Supporting the interpretation of the redshifts as intrinsic it was then found that the redshifts had discrete preferred values in the frame of their parent galaxy. (The Karlsson periodicity formula). The ejection velocities allowable are small compared to these intrinsic redshifts. They are observed to spread the redshifts around the preferred values by less than about +/- 0.1 in z. from their preferred values. Nevertheless that deviation from the periodic value can be used to test the prediction that the velocities are generally + and - in pairs, representing the approaching and receding velocities which would be necessary in order to conserve momentum in an ejection process. We test that prediction in the present paper by analyzing some cases in which several pairs of quasars surround a central, ejecting galaxy.

Three specific consequences follow:

- Firstly, since quasars are (by hypothesis) associated with specific active galaxies, then any redshift periodicity will only become apparent when the quasar’s redshift is corrected into the rest-frame of the parent galaxy.

- Secondly, the putative parent galaxies will be generally much brighter than their quasar off-spring;

- Thirdly, quasars of bright apparent magnitude will generally be nearby so that their associated parent galaxies will tend to be low-redshift objects. Quasars of faint apparent magnitude will generally be more distant so that their associated parent galaxies will tend to be higher-redshift objects. This implies that, generally speaking, the redshifts of quasars with bright apparent magnitude will require little or no correction for the periodicity effects to be manifested, whilst quasars with faint apparent magnitude will require considerable correction.

We begin by reviewing the history of redshift periodicity claims, and then consider the recent counter-claim by Hawkins, Maddox and Merrifield (2002) that, based on a large-scale analysis of the 2dF field, quasar redshift periodicity is not present. For this we first consider the overall 2dF data, pointing out that periodicity is apparent in the bulk data and then go on to consider, in detail, four sample fields of 2dF and SDSS. We conclude that the basic hypothesis is very much strengthened by the new large-scale surveys.

1.2 A Brief History

The existence of a preferred redshift of \( z = 1.95 \) for bright quasars was first pointed out by Burbidge and Burbidge (1967). Further periodicities were found by Lake and Roeder (1972) and Burbidge and O’Dell (1972). Karlsson (1971, 1973, 1977) showed that the formula \( \Delta \log_{10}(1 + z) = 0.089 \) provides a good fit to the major observed peaks at

\[
z = 0.30, 0.60, 0.96, 1.41, 1.96, 2.64...
\]

Karlsson established his fit with a sample of 574 quasars to a 99.9% confidence level. Later Barnothy and Barnothy (1976) confirmed this periodicity to the 99.99% confidence level. Depaquit et al. (1985) showed how every test to that date supported the Karlsson formula. With a larger sample of quasars Fang et al. (1987) again confirmed these
results. A few years later it was shown that the periodicity was particularly prominent for quasars which were close (by angular measure) to low redshift galaxies (Karlsson 1990; Arp et al. 1990).

It had also become clear by then that those low redshift galaxies with which such quasars appeared to be preferentially associated, tended to be morphologically disturbed and/or to have spectroscopically active nuclei. For example, the pairing of X-ray quasars across X-ray active Seyert galaxies demonstrated physical association at the 7.5 sigma level (Radecke 1997; Arp 1997).

Evidence continued to accumulate, culminating in the discovery of two active Seyfert galaxies, NGC 3516 (Chu et al. 1999) and NGC 5985 (Arp 1999) which had a total of eleven quasars accurately aligned along their minor axes. Ten of these clearly associated quasars fell close to the Karlsson peaks (see Arp 1998, p. 244, 284 - 285). Most recently Burbidge and Napier (2001) have tested the periodicity yet again with three different samples of quasars and found the fit to be significant at the $10^{-5}$ level.

The earlier studies, such as those discussed above, used largely bright quasars (and therefore nearby, according to the hypothesis) so that the associated (putative parent) galaxies had negligible redshifts. It follows that, for these samples, the periodicities (if they exist) would show up in the uncorrected redshifts. It is important to recognize that as early as 1990 it was understood that quasar redshift periodicity appeared to decline as quasar apparent brightness declined. This result became clear in the process of addressing the question of color selection effects in catalogued quasars.

Two different samples of quasars were tested by Arp, Bi, Chu and Zhu (1990). In the first sample, multiple quasars falling significantly closer than chance to low redshift galaxies were analyzed. The discovery criterion for these quasars was blue $U - B$ colours which were shown to be insensitive to redshift values. The significance of the peaks ranged from 94% to 99.5% for a sample size of 54 to 49 quasars. It was found, however, that the redshifts showed better correspondence to the Karlsson peaks when corrected for the redshift of the associated galaxy. The effect was small, however, because the redshifts of the associated galaxies were also relatively small.

The redshift transformation formula is the canonical one
\[
(1 + z_0) = (1 + z_Q)/(1 + z_G),
\]
where $z_Q$ is the observed quasar redshift and $z_G$ is the observed redshift of the associated galaxy which, by our hypothesis, is the ejecting galaxy.

The second sample analysed consisted of all radio quasars brighter than 1 Jansky at 11cm. It turned out in the end that this sample gave a fit to the Karlsson formula at a level of 99.997%. Of course, for quasars chosen on the basis of their strong radio emission there could be no question of color selection. But one thing was clearly stated in the Arp et al. 1990 paper and that was the redshifts "... become less clearly periodic as the radio strength declines. ..." Also, it was stated that: "Likewise the periodicity becomes less well marked fainter than $V \sim 18$ mag. ..."

With both the radio and optical apparent brightness diminishing it was reasonable to suppose that the quasars were becoming more distant. The parent galaxies with which they were associated would then be more distant and their redshifts would become non-negligible. The fainter quasars would need appreciable corrections to bring them into the rest frames of their parent galaxies. We would then expect any plot of quasar redshifts against apparent magnitude to show the periodicity better at bright magnitudes than at faint magnitudes. As we shall show, this is exactly what we find with the 2dF quasars.

### 1.3 Hawkins et al Analysis of 2dF QSOs

After all this, a sample of 1647 quasars close, by angular measure, to galaxies of otherwise arbitrary properties in the 2dF survey field of 289.6 sq. deg. was announced as showing no periodicity "at the predicted frequency. ... or at any other frequency." (Hawkins, Maddox and Merrifield 2002).
We note that the sole criterion employed by Hawkins et al to identify a parent galaxy was simply projected closeness on the sky of the galaxy to the quasars tested - thus, apart from the fact that, for the host of faint galaxies, there are very many more purely chance associations than for bright galaxies, critical criteria concerning the relative brightness and the state of activity of the chosen galaxies were not considered. In fact present investigations show the most significant associations of faint survey quasars is, for example, with UM strong emission line galaxies (Univ. Michigan objective prism survey). These parent galaxies are are in a brightness range around 15 to 18 mag. - not in the brightness range of the 2dF galaxies in which Hawkins et al. were attempting to test correlations.

2 The 2dF Fields

We show that quasar density plots in the apparent magnitude/redshift plane reveals the periodicity structure crudely but plainly, and in a way that requires no sophisticated statistical analysis to appreciate.

In essence, we proceeded as follows: The 2dF survey was conducted in two distinct declination strips: the declination strip $-2.5^\circ \leq \text{Dec.} \leq +2.5^\circ$ centered at about $RA = 12h15m$ contained in the first release 4200+ quasars. The declination strip $-32^\circ \leq \text{Dec.} \leq -27^\circ$ centered at about $00h30min$ contained 6700+ quasars.

For each declination strip, the whole region was divided into boxes $\Delta z \times \Delta B = 0.075 \times 0.3$ in the redshift/apparent magnitude plane, and the number of quasars per box counted. Figures 1 and 2 show density contours plotted through the fields. Since we are using the raw redshift data then, according to the basic hypothesis, at any given concentration level we should then expect to see contour spikes for the brighter objects near the Karlsson peaks $z = 0.3, 0.6, 0.96, 1.41, 1.96, \ldots$ whilst, for dimmer objects we should expect to see no signal at all. These expectations are met, as we describe below.

The declination strip $-2.5^\circ \leq \text{Dec.} \leq +2.5^\circ$ is plotted in Figure 1, and the outermost contour represents a density of 20 quasars per box whilst the innermost contour represents a density of 50 quasars per box. In this region (in the direction of the Local Super Cluster) we see strong bright-end spikes near $z = 0.6, 0.9, 1.5$ and 1.9. These are labelled $A$, $B$, $C$ and $D$ respectively.

The declination strip $-32^\circ \leq \text{Dec.} \leq -28^\circ$ is plotted in Figure 2 and the outermost contour represents a density of 27 quasars per box whilst the innermost contour represents a density of 65 quasars per box. In this region we see again strong bright-end spikes near $z = 0.6, 0.9, 1.5$. The situation near $z = 1.9$ is less clear. These are also labelled $A$, $B$, $C$ and $D$ respectively.

The really striking feature, of course, is the consistency of positioning between the $A$, $B$, $C$ bright-end spikes in both figures - it is this feature which makes it clear that these spikes are not functions of random variation in the data, but represent a real phenomenon. Together, they provide a strong, if noisy, confirmation of the reality of the Karlsson peak in quasar redshift data in the large sample presented in the first release of the 2dF.

2.1 The Final 2dF Release

After completion of this paper the final release of the 2dF fields took place (Colless et al 2003). It was thought interesting to see the foregoing analysis applied to the final data set. This is supplied here in Fig. 3 where all 22,435 QSO’s, in both the $\text{Dec.} = 0^\circ$ and $\text{Dec.} = -30^\circ$ strips together, are contoured in density steps of 102, 135, 165, 195 and 225. Again we see the peaks B, C and D roughly confirming the early release results.

It is clear, however, that in different regions different bright spikes are encountered and that with averaging over many regions they tend to become less distinct. For example in Fig. 3 there is a new prominent spike at a little greater than $z = 2.1$ labeled E. This can be identified with the quasars from a large region near the south galactic pole which is dominated by the Sculptor Group of galaxies. Between roughly $23h \leq R.A. \leq 01h$ and $-20d \geq \text{Dec.} \geq -40d,$
Figure 1: Apparent magnitude vs measured redshift plot for quasars in the 2dF survey declination strip centered on Dec = 0°. The contour lines represent quasar density where the outermost contours represent low densities, and the innermost contours represent high density. Note that peaks are only present for the brighter quasars.
Figure 2: Apparent magnitude vs measured redshift plot for quasars in the 2dF survey declination strip centered on Dec = -30°. The contour lines represent quasar density where the outermost contours represent low densities, and the innermost contours represent high density. The expected Karlsson peaks at 0.60, 0.96, 1.41, 1.96 are indicated.
Figure 3: Apparent magnitude vs measured redshift plot for quasars in the 2dF final release (22,435 QSO’s). The canonical Karlsson peaks at 0.60, 0.96, 1.41, 1.96 are indicated by their letter positions in Figs 1 and 2. An additional peak at $z \sim 2.1$ is also indicated, as noted in text.
objective prism surveys in strips across this region showed concentrations of $z \geq 2$ quasars. (Osmer and Smith 1980; Arp 1983; 1984). The current 2dF strip across this region confirms this previously discussed concentration of quasars.

However, it is also clear from these contour plots that even selecting a bright subsample that was sufficiently large to include all four bright-end spikes (typically, $B_{\text{mag}} < 19.6$) would not produce a sample that was sufficiently clean that a simple technique like power spectrum analysis would detect the periodicity signal implied by the $A, B, C, D$ spikes. For example inclusion of somewhat fainter, uncorrected quasars moved the predicted peaks in Figs. 1 and 2 toward $z = .65, 1.02, 1.48$ and 2.05, (as predicted by the results of Arp et al. 1990, especially Fig. 3a and 3b of that paper). For much fainter apparent magnitude quasars the parent galaxies would have a much wider range in redshift and the raw quasar redshifts would be expected to approach a smooth distribution as is, in fact, born out by the contours at faintest apparent magnitudes in Figs. 1, 2 and 3.

It would seem that, for the basic hypothesis to be comprehensively demonstrated, it is necessary to attempt the association of quasars with their respective ‘parent’ galaxies, so that the quasar redshifts can be transformed into the appropriate rest frames. For this purpose, there would seem to be no substitute for actually looking at the fields which are being tested to see what kinds of galaxies there are in those fields, and how the quasars are actually distributed with respect to those galaxies.

### 3 A Test in a Field of the Sloan Digital Sky Survey

In the following, we use a single field from the SDSS (Abazajian et al. 2003) to make the point that whereas a naive analysis would find no evidence of periodicity, a more critical analysis which paid full attention to the basic hypothesis would find it to be very strongly confirmed on this single field.

The field to be considered, which is in the vicinity of the active ($z = 0.017$) Markarian galaxy NGC 622, was chosen for two reasons:

- firstly, prior to the SDSS, there were known to be Karlsson-peak quasars at $z = 0.91$ and 1.46 only 71″ and 73″ away (Arp 1981; 1987).
- secondly, in the intervening years, the SDSS survey has identified further quasars in the general vicinity of NGC 622 which have not been previously examined.

However, the problem is complicated by the fact that the general field which contains all these newly catalogued quasars also contains another bright ($V = 16.6 \text{ mag}$) active galaxy - the Seyfert UM 341 ($z = 0.399$) - which is also a putative parent galaxy for any quasars in the vicinity. What we shall show is that all of the catalogued quasars within approximately 35 arcmins of either of these two bright objects is a Karlsson peak object relative to one or the other of them.

Table 1 lists all catalogued quasars within 33′ of NGC 622 - with the exception of two objects which we associate with UM 341. Table 2 lists all catalogued quasars which lie within 36′ of UM 341. Fig. 4 shows a 40′ radius field centered on UM 341, with all the SDSS objects included. Note: Fig. 4 does not show all the NGC 622 objects, but does include two Karlsson-peak quasars (bottom $z = 1.46, 3.63$) not listed in either table. These two are omitted because, although they are Karlsson peak objects in the frame of NGC 622 (or in the frame of either of the other two $z = 0.017$ objects in the field), they lie outside the chosen 33′ radius circle associated with NGC 622.

Tables 1 and 2 quantify the situation. Table 1 lists all the NGC 622 objects, showing raw redshift data in the $z$ column, corrected redshift data in the $z_0$ column and the difference between $z_0$ and a Karlsson peak in the $\Delta z$ column. Table 2 does the same for the bright Seyfert object, UM 341.

In total, the two tables show all sixteen of the corrected quasar redshifts lie, on average, within 0.049 of a Karlsson peak. When we realize that the expected deviation from the low-value peaks ($z = 0.3$) is about 0.075 and from the
Figure 4: Simbad map showing all catalogued galaxies and quasars within 40' of UM341 (center). Open circles are Karlsson peak quasars in the frame of NGC 622 (or the other $z = 0.017$ galaxies). Filled circles are Karlsson peak quasars in the frame of the central bright Seyfert, UM341 ($z = 0.399$)

Table 1: Quasars Associated with NGC 622

| Name   | mag. (g) | $z$  | $z_0$ | $\Delta z$ peak | Remarks     |
|--------|----------|------|-------|-----------------|-------------|
| NGC 622 | m = 14.1 | .017 | ——    | ——              | Mrk 571 parent |
| UB1     | 18.4     | 0.910| .88   | -.08            |             |
| BS01    | 19.0     | 1.460| 1.43  | +.02            |             |
| SDSS    | 18.9     | 1.501| 1.46  | +.05            |             |
| SDSS    | 19.3     | 2.749| 2.69  | +.05            |             |
| FIRST   | 17.8     | 0.344| .32   | +.02            | Radio Gal   |
| SDSS    | 18.6     | 1.522| 1.48  | +.07            |             |
| SDSS    | 19.2     | 1.049| 1.01  | +.05            |             |
Figure 5: The Seyfert object (UM 341) and the seven nearest quasars associated with it. The quasar redshifts are transformed into the rest frame of the central Seyfert object. The difference between this redshift ($z_0$) and the nearest peak in the periodicity is written below the redshift.

Table 2: Quasars Associated with UM 341

| Name   | mag. (g) | $z$  | $z_0$ | $\Delta z$ peak | Remarks         |
|--------|----------|------|-------|-----------------|-----------------|
| UM 341 | 16.6     | .399 | --    | --              | Seyfert parent  |
| SDSS   | 18.4     | 1.666| .91   | -.05            |                 |
| SDSS   | 18.6     | .718 | .23   | -.07            |                 |
| 4C V = 21.7 | .879 | .34  | +.04  | +.04            | PKS B–V=.84     |
| SDSS   | 19.0     | .745 | .24   | -.06            |                 |
| UM 339 | 18.2     | 1.31 | .65   | +.05            |                 |
| SDSS   | 19.3     | 1.805| 1.01  | +.05            |                 |
| SDSS   | 21.9     | 3.183| 1.99  | +.03            |                 |
| SDSS   | 19.1     | .734 | .25   | -.05            |                 |
| SDSS   | 19.1     | .781 | .27   | -.03            |                 |
highest value peaks \((z = 2.64)\) is about 0.17, and given that the field was chosen because one of us (Arp) has already considered the same field many years ago when it contained only two quasars, we can see that this is a result having an extremely low probability of being a chance result.

It is important to point out here that we introduce in the appendix a new analysis which simultaneously measures the goodness of fit of the redshifts to the periodicity law and the probability of finding the redshift of the parent galaxy as measured.

At his stage, however we already would like to emphasize that a partition of the sixteen quasars by their Karlsson peak properties corresponds closely to a partition according to their geometric association with each of UM341 and NGC622. Consequently if we had just done what was done in the highly publicized Hawkins et al paper, then a negative result would most certainly have been obtained. The essential point is that Quasars must be correctly identified with their putative parent galaxy, and moved into the rest-frame of that galaxy, if the Karlsson peaks are to be observed.

3.1 Geometric Centering of Putative Parent

This type of disposition is observed in Fig. 4 where it is seen that the Seyfert is roughly at the center of very similar redshift quasars, \(z = 0.72\) to 0.78. In addition to this, the basic hypothesis leads us to expect (for reasons of momentum conservation) that quasar ejection events will tend to occur as paired events with paired objects being ejected in opposite directions.

When looking just around UM 341 it is discovered that the inner four quasars form two rather well aligned pairs across the central Seyfert. They are marked in Fig. 5. It is seen that the deviations from the Karlsson peaks tend to be positive on one side of the pair and negative on the other. This is what would be expected if the pair were ejected with a radial component of approaching velocity on one side and receding on the other. Moreover the centering of the active galaxy is fairly good and the quantitative values of the \(\Delta z's\) are closely equal (e.g. \(+.05\) and \(-.05\) across one pair).

It is also to be noted in Fig. 5 that the rest of the quasars around UM 341 are roughly aligned and the calculated ejection velocities are positive on the SW side and negative on the NE side.

Do such ejection velocities have any independent precedent? Using the calculation

\[
1 + z_v = (1 + z_0)/(1 + z_{peak})
\]

The actual current velocities compute to \(\pm 7650 \text{ km/sec}\) and \((+9230, -16150) \text{ km/sec}\) for the innermost two pairs. These velocities are of the order of 10000 \text{ km/sec}, similar to ejection velocities calculated for most of the highly significant pairs ejected from well known Seyfert galaxies (Arp 1998). Recent measurements of the initial outflow of the ionized material from the QSO/Seyert PG1211+143 give \(.08\) to \(.10c\) (Pounds et al. 2003a,b). So there are direct confirmations of such velocities.

Many similar examples of ejection are presented in a new Catalogue of Discordant Redshift Associations (Arp 2003).

4 Visual Surveys in Three 2dF and SDSS Fields

We should emphasize that the procedure we are following is to examine apparent groups and concentrations of quasars that appear to be physically associated. In each of the cases investigated here it turns out there is a brighter, active galaxy present which is a candidate for the origin of these quasars. We then proceed to test this identification by seeing whether the disparate redshifts are brought into the order of the Karlsson formula when their redshifts are transformed to this chosen parent.
We began by selecting three regions, chosen for reasons independent of the current considerations, from the 2dF and SDSS surveys. Then, we simply performed an elementary visual inspection of quasar distributions within these fields, looking for the typical configuration signatures that the basic hypothesis leads us to expect.

4.1 Region Selection Criteria

The regions were selected by one of us (Fulton) from the 2dF and SDSS surveys for an MSc study in data-mining which was completely independent of the present analysis (Fulton 2002). For illustration of the data-mining technique, it was decided that a comparative study of galaxy distributions and quasar distributions over the same areas of sky would be ideal. Thus, a requirement for reasonably complete surveys of both galaxies and quasars in the chosen areas was generated. Since the Fulton study was using early releases of 2dF data, this imposed particularly tight constraints on the choice of suitable 2dF fields.

Fulton was able to locate one suitable region from SDSS and two from 2dF. These regions are:

- 2dF region 1: Centered on RA(23h24m30s) and Dec(−28d33m36s) and covering about 6 square degrees;
- SDSS region 2: Centered on RA(09h50m00s) and Dec(00d00m00s) and covering about 10 square degrees;
- 2dF region 3: Centered on RA(13h41m) and Dec(−01d30m00s) and also covering about 6 square degrees.

4.2 Region 1 - A 2dF Field.

The basic hypothesis leads us to expect the existence of strings/groups of quasars associated with bright active galaxies. A visual examination of Fulton’s region 1 leads to a straightforward identification of such an apparent grouping within a 35′ circle, centered on RA(23h11m30s) and Dec(−28d15m00s). Simbad was used to get a complete listing of all the other objects in this field, which is shown with all its catalogued contents in Fig 6. It is clear that the quasars in the field form a rather dense cone-like distribution having at its apex the very bright and very low redshift object NGC 7507 and the companion galaxies that make up its group (Arp/Madore 2309-284). If NGC 7507 is taken as the putative parent then, according to the basic hypothesis and since this object has an extremely small redshift at $z = 0.005$, we should expect to find a strong bias to the Karlsson peaks in the raw data.

In Figure 6 the observed redshifts are written next to each quasar. Filled circles indicate redshifts falling within the 50% probability circle around the Karlsson peaks (that is, within a region $±0.022$ centred on each peak on the $\log_{10}(1 + z)$ axis), and open circles indicate redshifts falling outside the 50% circle. It is clear that the quasars stretching up to the NW from NGC 7507 are almost all near the Karlsson peak values.

The actual distribution of these redshifts relative to the Karlsson peaks is shown in Figure 7. The numerical probability of this observed distribution being due to chance is discussed in Appendices A and B.

But in addition to the high probabilities for the realities of the periodicity, the physical association of these quasars with the bright galaxy is reinforced because it is possible to draw a cone shaped perimeter, with NGC 7507 at one end, which contains 15 quasars, only one of which does not fall near a Karlsson peak. It seems that this would strongly support the ejection origin for the excess number of quasars from this very low redshift ($z = .005$), bright galaxy.

There are two quasars close to the SSE of NGC 7507 in Fig. 6 but further to the SE there is a paucity of 2dF quasars as if we were seeing background values. There are some active galaxies which appear to have one sided ejections, for perhaps the same reasons that there are one sided jets from galaxies. One could suggest that ejections in certain directions are deviated or broken up upon exiting through certain portions of the parent galaxy.
Figure 6: 2dF quasars inside a 35′ circle centered at 23h11m30s -28h16m00s. Redshifts near the Karlsson peaks are indicated by filled circles, redshifts between peaks are indicated by open circles. NGC 7507 is the principle galaxy in a group with redshift $z = 0.005$.

Figure 7: The distribution of probabilities of the redshifts falling close to the peaks for all the quasars in Fig 6. Open circles illustrate redshifts falling away from the peaks, filled circles the 21 quasars falling close to the peaks.
Figure 8: All SDSS quasars falling within 30′ of the NGC 3023 (z = 0.006) group (radio galaxies plus Mrk 1236 (z = 0.006)). The principle pair is at z = 0.64 and z = 0.584 (both double radio sources). Redshifts and z_v differences from Karlsson peaks are written next to quasar symbols.

4.3 Region 2 - An SDSS Field

The basic hypothesis requires that Karlsson peak quasars are associated with specific putative parent active galaxies that, generally speaking, will be much brighter than their offspring quasars. The general ejection picture suggests that, commonly, we should find quasars with matching redshifts paired across their putative parents, and many such configurations are already known. (Arp 1967; E.M. Burbidge 1995; Arp et al. 2001). By contrast, if we accept the canonical viewpoint about quasars, then such configurations should be very rare.

It is notable, therefore, that one such configuration is readily identifiable in Fulton’s Region 2: We consider a 30′ circle, centered on RA(09h49m48s) and Dec(00d37m30s) from this region. Fig. 8 shows six quasars in a field of radius 30′ which are centered on the active triplet of low-redshift galaxies around NGC 3023 (z = 0.006). The outstanding pair consists of z = 0.640 and z = 0.584 quasars which fall z_v = +0.02 and −0.02 from the major redshift peak at z = 0.60. It would be difficult to avoid the implication that they had been ejected from one of the central galaxies and were now travelling with a radial component of velocity 0.02c, one away from, and one toward the observer.

Moreover, there are two other pairs of quasars in approximately the same direction. One pair has apparent velocity deviations from the redshift peaks of z_v = +0.09 and −0.07 and the other z_v = +0.03 and −0.06. This pattern is characteristically encountered (e.g. see UM 341 in the NGC 622 field and pairs analyzed in the introduction to “A catalogue of Discordant Redshift Associations” (Apeiron 2003). The chances would seem vanishingly small to find repetitions of such patterns in random associations of background objects. In the present case, however, there is even more evidence for association in the fact that both members of the major pair at z_peak = 0.60 are strong radio sources. The central galaxies are both NVSS radio sources and the two quasars are each double radio sources. The latter is quite unusual and represents additional evidence against accidental association.

It should be noted that the central galaxies here are low redshift so that only small corrections to their rest frames
Figure 9: *UM* 602, a bright QSO/Seyfert object is the center of six quasars which are close to the $z = 2.64$ Karlsson peak. When transformed to the $z = 0.236$ redshift of *UM* 602 the mean redshift of the six comes out $z = 1.94$, close to the Karlsson peak of $z = 1.96$.

are needed.

### 4.4 Region 3 - A 2dF Field

Finally, the software was used in an experiment to see whether we could find an example of a group of quasars all at the same Karlsson peak. The point was to see if there was a bright, active galaxy assignable to the origin of the group. We found the string of $z = 2.64$ (±0.1) quasars pictured in Fig. 9. We were pleased to find a bright Seyfert/QSO at the center of this string.

But unfortunately (or so it seemed), the bright Seyfert/QSO had a large redshift of $z = 0.236$, which seemed certain to destroy the Karlsson peak coincidence, after the rest-frame transformation. However, when the six quasar redshifts were transformed into the rest-frame of *UM* 602, they became $z = 1.92, 1.99, 2.02, 1.86, 2.01, 1.86$ (mean value $z = 1.94$). These are all clustered around the major Karlsson peak at $z = 1.96$ (first discovered at 1.95). Moreover the innermost quasars form rather well aligned pairs across UM 602. One pair is $z = 2.72$ and $z = 2.73$, the other pair is $z = 2.54$ and $z = 2.54$.

### 5 Objects With Two Redshifts

In a discussion of spectra in the 2dF fields, Madgwick et al. 2002 reveal the occurrence of a low redshift galaxy of $z = .16$ and a quasar *in the same spectrum* of $z = .87$! They note it is "a spectrum showing evidence for a low redshift galaxy and a quasar at much higher redshift" but with no evidence for a gravitational lens. It is interesting to note that if the quasar is physically associated with the galaxy its redshift would be transformed into $z = .61$, very near the Karlsson peak of $z = .60$. This is also support for the result of Burbidge and Napier 2001 who tested, with positive results, redshift periodicity in apparent pairs of quasars separated by $\leq 10^\circ$. 


Figure 10: NGC 622 is the bright Seyfert at the center of seven quasars in Fig. 3. When transformed to the rest frame of galaxies having a range of redshifts, the residuals from the nearest Karlsson peaks (measured in $z'_v$s) assumes a deep minimum at $z = .024$. The actual redshift of NGC 622 being $z = .017$ indicates the association is unlikely to be chance and that standard periodicity is accurately fitted. Absolute values of the residuals are plotted as dots.

Another case of two redshifts in one spectrum is 3C343.1, a radio galaxy with a bridge to a quasar which is only .25 arcsec distant. The galaxy has $z = .344$ and the quasar $z = .750$. When transformed to the $z = .344$ galaxy, however, the quasar redshift becomes $z_0 = .302$ which is rather close to the Karlsson value of $z_{peak} = .30$ (Arp, Burbidge and Burbidge , 2004.)

6 Summary

For over 35 years now the evidence has been building for a set of numerically defined peaks in the distribution of quasar redshifts - the so-called Karlsson peaks. But the existence of the Karlsson peaks has generally not been acknowledged - primarily because of the serious implications for canonical cosmology.

The new large scale 2$dF$ and 2$SDSS$ surveys offer the opportunity to settle the issue finally using quantitative statistical methods - but, because of the fundamental importance of the claims, it is crucial that such large scale studies are rigorously designed and executed.

We emphasize (a) that evidence supporting the basic hypothesis is readily found in the new surveys and (b) what is required is a rigorous analysis of the areas investigated. We have made a variety of tests in sample areas of these surveys and have found that periodicity of redshifts is strongly present in contiguous groups of quasars - but only in the reference frame of the associated, dominant galaxy. This result not only strengthens the universality of the periodicity relation but also confirms the physical association of higher redshift quasars with relatively low redshift, generally brighter galaxies. The parent galaxies further confirm the physical associations by turning out to be generally emission lines objects, often morphologically disturbed and often showing X-ray and radio emission.

A Analysis of Periodicity by a Method of Minimum Residuals

The question arises as to whether it is possible to test quasars in a group around a candidate parent galaxy against control fields or by monte carlo methods. It turns out there is, by the simple expedient of transforming redshifts to the rest frame of the presumed parent galaxy and then varying the redshift of that parent. We have done that here
Figure 11: UM 341 is the Seyfert at the center of nine quasars in Fig. 4. When transformed to the rest frame of galaxies having a range of redshifts, the residuals from the nearest Karlsson peaks (measured in $z_{v}'$,s) assumes a deep minimum at $z = .385$. The actual redshift of UM 341 being $z = .399$ indicates the association is unlikely to be chance and that standard periodicity is fitted with great accuracy. Another minimum almost as well defined, at $z = .125$, is almost exactly one Karlsson period away.

by transforming the quasar redshifts listed for NGC 622 and UM 341 in Tables 1 and 2 to $z_o$ by means of the redshift of the central galaxy, then computing $z_v$, the component of velocity needed to explain its deviation from the nearest, exact redshift peak. We then compute the same $z_v$’s after transforming the observed redshifts to a large range of different parent redshifts.

The results are shown in Figs. 10 and 11. Plotted are the mean of the absolute values of the residuals, $<|z_v|>$, from the periodicity formula (plotted as dots). Plotted also are the mean values of the residuals, $<z_v>$, with plus for a positive and minus for a negative residual. What we see in Fig. 10 is that the scatter for the absolute values of the residuals remains large throughout the tested range. But at a low redshift, about that of the parent, $z = .02 - .03$, the scatter reduces to about .03 to .04 and the residuals then start a smooth convergence, systematically positive, reducing toward zero and then increasing negatively on the other side of a sharply defined position where the receding and approaching ejection velocities are at a minimum and exactly balanced between plus and minus.

That value in Fig. 10 is about $z = .024$. This is to be compared to the actual value of the observed parent galaxy of $z = .017$. This is the only value in the tested range which gives a very close fit to the Karlsson formula series of redshift peaks. It seems that we have shown that this group of disparate redshifts shows almost perfect correspondence to the periodicity peaks but only when transformed to a redshift frame very close to the previously assigned parent redshift.

Fig 11 shows a similar analysis applied to the nine quasars around UM 341. Here we see two places where the absolute values of the residuals becomes very small and the the plus and minus values balance at zero. One is $z = .385$, close to $z = .399$, the observed value for UM 341. The other is $z = .125$, almost as good a minimum, and interestingly, $(1 + .385)/(1.23) = (1 + .126)$, an almost exact Karlsson interval distant. The latter suggests that the Karlsson period remains exact even when the parent galaxy falls somewhat inexactly on a peak.

A word should be mentioned about the plus and minus signs between minima. When the transformed z’s transit from one peak to the next their residual is at a maximum but suddenly changes sign, affecting the mean strongly. It is
not until the residuals are all small, that the plus and minus $z_v$'s accurately measure the convergence of balanced plus and minus ejection velocities. The absolute value of the residuals has a shallow minimum no more than $<|z|> = 0.03$ suggesting that it is the average projected ejection velocity which then must average to near zero in pairs of oppositely ejected quasars. That average projected velocity is comparable with the measured outflow velocity of ionized material close to AGN quasars, e.g. $z = 0.08$ to $0.10$ (Pounds et al. 2003).

When the minimum residual analysis is applied to the 27 quasars in the field of NGC 7507 (residual plot not shown here) the minimum is clearly at $z = 0.005$, the measured redshift of the parent galaxy. When it is applied to just the 15 quasars in the cone going NW, however, the minimum at $z = 0.005$ becomes sharper and more conspicuous. In the probability analyses of Appendix B to follow, a power spectrum analysis of the 27 quasars in this 2dF field is shown.

A.1 A group of quasars south of NGC 2639

Finally we should mention that this same analysis can be applied to a group of 10 quasars south of the bright Seyfert, NGC 2639, discovered in the era when quasar detection was done by ultraviolet excess (Arp 1980). In this case the minimum residual analysis is now especially accurate in picking out the actual redshift of the real parent and confirming the behavior of the residuals. In Fig. 12 we show the distribution and redshifts of the QSOs around the companion galaxy which has $z = 0.006$. Arp originally argued that these QSOs originated in that companion. However, a spectrum of this galaxy shows only absorption lines and thus no sign of nuclear activity (Arp 1980).

We consider instead the possibility that these QSOs have originated from the brightest active system in their vicinity which is the QSO with $z = 0.305$. We have tested this hypothesis by transforming the observed redshifts into the two reference frames, dividing by 1.006 and then by 1.305. The results are given in Table A1.

We can then see which set of transformed redshifts fits the periodicity peaks best. The answer is given at the
Table 3: Quasars South of NGC 2639

| Quasar | z   | z(0.006) | z_v  | z(0.305) | z_v  |
|--------|-----|----------|------|----------|------|
| U 10   | 0.305 | 0.297    | 0.000 | —        | —    |
| U 8    | 2.800 | 2.780    | + 0.040 | 1.912   | - 0.02 |
| U 3    | 1.522 | 1.507    | + 0.040 | 0.933   | - 0.01 |
| U 1    | 1.177 | 1.164    | + 0.100 | 0.668   | + 0.04 |
| U 2    | 1.105 | 1.092    | + 0.070 | 0.613   | + 0.01 |
| U 4    | 0.780 | 0.769    | + 0.106 | 0.364   | + 0.05 |
| U 5    | 1.494 | 1.479    | + 0.030 | 0.911   | - 0.02 |
| U 7    | 2.000 | 1.982    | + 0.010 | 1.300   | - 0.05 |
| U 14   | 2.132 | 2.114    | + 0.050 | 1.400   | 0.00  |
| U 15   | 1.535 | 1.520    | + 0.050 | 0.943   | - 0.01 |

< z_v > = +0.03 to +0.05  < z_v > = +0.00
< |z_v| > = 0.049  < |z_v| > = 0.023

bottom of the 4th and 6th columns. It shows that the relative velocities measured by z_v for the companion case are all positive. (Except for U4 which sits just on the edge between two Karlsson peaks). On the other hand the plus and minus values exactly balance for the z = 0.305 case. This means the average ejection velocities in the approaching and receding directions average to zero as they should if they are associated with this QSO. (The same argument holds if the residuals are not velocities but represent intrinsic scatter around a peak.) Also the absolute size of the residuals needed to correct the redshifts on to the intrinsic peaks are only half as large than when it is assumed that the z = 0.006 galaxy is the progenitor.

In order to further illustrate the significance of the periodicity present in the redshifts of the group of QSOs south of NGC 2639, we now plot the residuals from those redshifts in the rest frame of a range of possible parent galaxies. Fig. 13 shows that the deviations from the Karlsson periodicities reach a very sharp minimum exactly at z = .305, the redshift of the actual AGN/QSO that we have assigned as the parent of this group.

It is also apparent that there is a secondary minimum for a parent at z = 0.062, not quite as good as the z = 0.305 but very similar and exactly one Karlsson period away from z = 0.305. Early studies of low redshift QSOs and AGN suggested that the first intrinsic redshift peak lies at z = 0.061 (Burbidge 1968). In a later sample Arp et al. (1990) obtained z = 0.062.

A similar situation suggesting secondary ejection might also be true for the northern QSO with z = 0.323 which is paired with the z = 0.305 QSO across NGC 2639. However, to test this it would first be necessary to search for QSOs around this object, and so far this has not been done.

Here we must gratefully acknowledge the remeasuring of six of the quasars in the NGC 2639S group which resulted in correction of two of the original 10 redshifts (Ford, H. et al. 1983). These corrections helped make the fit of the quasars to the periodicity, and their association with the parent, so precise in the present paper.

In all, this analytical procedure raises interesting opportunities to study the mathematical behavior of the Karlsson periodicities as manifested by parents of different redshifts. Taking a group of quasars of apparently unrelated redshifts, making the required transformation to the redshift of the candidate parent galaxy and then finding the redshifts to fit a previously well defined formula, would seem to confirm at a very high level of probability the periodicity relation as well as demonstrating again the physical association of specific low redshift galaxies with high
Figure 13: The AGN with $z = .305$ (southern of the pair across NGC 2639) is taken as the ejecting parent of the nine quasars in Fig. 12. When transformed to the rest frame of galaxies having a wide range of fictitious redshifts, the residuals from the nearest Karlsson peaks (measured in $z'_{s}$) assumes a deep minimum just at $z = .305$. Therefore the association is extremely unlikely to be chance. The standard periodicity is thus fitted with great accuracy by this group of quasars discovered in 1980. A secondary minimum at $z = .062$ is exactly at the next Karlsson peak lower. The residuals are given near the minima as + and - symbols. The absolute values of the residuals are given as dots.

B Numerical Estimates of Probability

In the fields around NGC 622 and UM 341 we note that on the log$_{10}(1 + z)$ axis the Karlsson period is 0.089, so that the expected deviation from a peak-value is about 0.022. The mean actual deviations of the $\Delta z$’s is 0.012, and a very conservative calculation of the odds of all fourteen of the new quasars being a Karlsson peak quasar relative to either one of NGC622 or UM341 gives a probability of $2.6 \times 10^{-5}$ of it being a chance occurrence.

In more detail, we ask the following question: given the existence of the two bright active independent objects, NGC622 and UM341 in the field of figure Fig. 4 and the two existing Karlsson peak quasars (Arp 1981, 1987) adjacent to NGC622, what is the probability of fourteen out of fourteen new quasars turning out to be Karlsson peak objects for either one of NGC622 or UM341?

We proceed as follows: the expected dispersion of measured redshifts from the nearest Karlsson peak along the log$_{10}(1 + z)$ axis, given that there is no effect, is 0.022. In fact, the actual mean dispersion is 0.012, and the odds of any one quasar falling that close to a Karlsson peak after being transformed into the frame of, say NGC622, is about 0.27 - given that there is no effect.

But, the quasar might be a Karlsson peak object for either of NGC622 or UM341, and since we allow ourselves this possibility, it must be accounted for. The probability of this dual eventuality is easily calculated to be about 0.47. Since we have fourteen such quasars, the overall probability is now estimated as $0.47^{14} = 2.6 \times 10^{-5}$.

This calculation is highly simplified of course, but it is to be noted that no account is taken of the pairing redshift quasars.
configuration of Figure 5 - even though such configurations are to be expected in terms of the basic hypothesis and not to be expected if the quasars are unassociated. Thus the true probabilities of finding what is observed are very much smaller than we actually calculate.

As for the results shown in Figs. 6 and 7, one approach would be to reason that if the redshifts were not related to the specific periodicity peaks one would expect equal probability of the points in Fig. 7 falling anywhere in the interval $P = 0$ to 1 with a mean at $P = .5$ - i.e. a horizontal line. The histogram shows, however, an excess of 14 points with $P = .28$ and less. The chance of this can be roughly calculated as $P(.28)^{14}/P(.5)^{14} = 3 \times 10^{-4}$.

Alternatively we could estimate the probability of the configuration arising by chance, by noting that of the 27 quasars in the field, 17 of them actually fall within the 28% circle around the Karlsson peaks and 10 fall outside. Simple binomial statistics then gives the probability of this configuration arising by chance, as $1.5 \times 10^{-4}$.

Finally Fig. 14 gives a power spectrum analysis of the 27 quasars in the region around NGC 7507 as shown in Fig. 6. The period is $P = .083$ and the power $I = 15.0$. I

![Power spectrum analysis of quasars in the NGC 7507 region which is pictured in Fig. 6. Power is around $I = 15$ and period is close to Karlsson period (see text).](image)

If we then test just the quasars in the NE cone emanating from NGC 7507, the period becomes $P = .086$ and $I = 15.6$. The canonical Karlsson value for the periodicity is $\Delta log(1 + z) = .089$.

All of these various tests appear to give a significant result in agreement with the visual impression.

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