No Periodicities in 2dF Redshift Survey Data

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ABSTRACT

We have used the publicly available data from the 2dF Galaxy Redshift Survey and the 2dF QSO Redshift Survey to test the hypothesis that there is a periodicity in the redshift distribution of quasi-stellar objects (QSOs) found projected close to foreground galaxies. These data provide by far the largest and most homogeneous sample for such a study, yielding 1647 QSO–galaxy pairs. There is no evidence for a periodicity at the predicted frequency in log(1 + z), or at any other frequency.

Key words: quasars: general – large scale structure of Universe

1 INTRODUCTION

Claims of periodicities or regularities in redshift distributions of various astronomical objects have been made for many years (e.g. Burbidge & Burbidge 1967; Broadhurst et al., 1990; Karlsson, 1990; Burbidge & Napier, 2001). This effect, if real, has far-reaching implications for the interpretation of redshift as a cosmological phenomenon, and, indeed, for the nature of objects like quasi-stellar objects (QSOs) that appear to display the periodicities.

One particularly intriguing effect has been explored by Arp et al. (1990) and Karlsson (1990) and extended to a larger sample by Burbidge & Napier (2001). It involves the apparent strong periodicity in log(1 + z_{qso}) for a sample of QSO redshifts, z_{qso}, where the QSO appears projected close to a “foreground” galaxy at lower redshift. If confirmed, such an effect would be impossible to explain in conventional cosmological terms: it would either require that the QSOs be physically associated with the galaxies in an as-yet unexplained fashion, or that the QSO light passing the galaxy is somehow influenced to quantize its redshift.

The criticism usually levelled at this kind of study is that the samples of redshifts have tended to be rather small and selected in a heterogeneous manner, which makes it hard to assess their significance. The more cynical critics also point out that the results tend to come from a relatively small group of astronomers who have a strong prejudice in favour of detecting such unconventional phenomena. This small group of astronomers, not unreasonably, responds by pointing out that adherents to the conventional cosmological paradigm have at least as strong a prejudice towards denying such results.

In an attempt to circumvent these problems, Bill Napier contacted the authors of this paper. The availability of the data from the 2dF Galaxy redshift Survey (2dFGRS) and the 2dF QSO Redshift Survey (2QZ) means that for the first time there exists a large homogeneous sample of data to carry out this kind of study. Furthermore, Napier recognized the importance of the study being carried out independent from any of the researchers with vested interests one way or the other. He therefore gave clear instructions as to what analysis should be performed and what periodic effect should be seen if the phenomenon is real, but chose to take no part in the subsequent analysis. We have attempted to carry out this analysis without prejudice. Indeed, we would have been happy with either outcome: if the periodicity were detected, then there would be some fascinating new astrophysics for us to explore; if it were not detected, then we would have the reassurance that our existing work on redshift surveys, etc, has not been based on false premises.

The remainder of this paper is laid out as follows. Section 2 presents Napier’s prediction as to what signal we should expect to see if the data are analysed appropriately. Section 3 describes the data set, and Section 4 presents the manner in which it has been analysed. The results are described in Section 5.

2 NAPIER’S PREDICTION

In briefing us, Bill Napier stated that a strong periodicity had been found in the redshifts of QSOs projected within 30 arcmin of the centres of nearby galaxies (either in the Virgo Cluster or bright galaxies in the Shapley Ames Catalog), corresponding to a physical scale of ~ 200 kpc at these galaxies’ distances. He therefore suggested that we look at all galaxies in the 2dFGRS, use their redshifts to estimate their distance (adopting a Hubble constant of 60km/s/Mpc), and find all QSOs from the 2QZ survey projected within a circle whose radius corresponds to 200 kpc at the galaxy’s distance. Then, after transforming the QSOs’ redshift to
the reference frame of the galaxies that they lie behind, we should expect to find a strong periodic signal in log(1 + z) at a period \( P \approx 0.09 \).

3 THE 2DF DATA

3.1 The parent catalogues

For this study, we use the large databases provided by two surveys carried out using the 2dF multi-object spectrograph on the Anglo-Australian Telescope (Lewis et al. 2002). For the galaxies, we use the publicly available 100k data release from the 2dF Galaxy Redshift Survey (Colless et al. 2001) and for the QSOs we take the publicly available data from the 10k 2dF QSO Redshift Survey (Croom et al. 2001). These two surveys used shared observations to measure the redshifts of well-defined samples of galaxies and QSOs in a common region of the sky, making them ideally suited to this analysis.

To ensure the reliability of our sample we only use galaxies from the 2dFGRS with the two highest quality flags, \( Q \geq 4 \), in order to have confidence in the derived redshifts, and consider only those galaxies in the range \( 0.01 < z < 0.3 \). For the 2QZ sample we only use QSOs with the highest quality flag in the database, which implies a clear spectral identification of the object as a QSO. This quality control leaves a total of 67291 galaxies and 10410 QSOs in the samples.

The survey strategies and the limitations of the 2dF instrument mean that the selection of objects in the galaxy and QSO surveys are not entirely independent. For example, the diameters of the individual fibers mean that very close pairs of objects are sometimes missed. However, none of these geometric selection criteria depend on the redshifts of the galaxies or QSOs, so although the sample may be somewhat incomplete, its redshift distribution will not be biased in any way by the selection process.

3.2 Pair selection

As instructed, we have inter-compared these datasets to find all QSO-galaxy pairs with an angular separation corresponding to less than 200 kpc at the distance of the galaxy. For this calculation, we adopt the fashionable \( \Lambda \) cosmology, with parameters \( \Omega_m = 0.3, \Omega_\Lambda = 0.7 \) and \( H_0 = 60 \text{km s}^{-1} \text{Mpc}^{-1} \). However, the relatively low redshifts of the foreground galaxies means that the choice of cosmology makes essentially no difference to the sample selection. In a number of cases there is more than one galaxy within the 200 kpc projected distance limit of the QSO; for these objects we take the closest galaxy in projected distance to make up the pair. In a few cases, the same galaxy may be used for more than one QSO. This procedure yields a total of 1647 QSO-galaxy pairs.

The predicted periodicity lies in \( \log(1 + z_{\text{eff}}) \), where \( z_{\text{eff}} \) is the redshift of the QSO measured relative to the nearby galaxy, so we define

\[
1 + z_{\text{eff}} = (1 + z_{\text{qso}})/(1 + z_{\text{gal}}),
\]

where \( z_{\text{qso}} \) and \( z_{\text{gal}} \) are the corresponding heliocentric measurements for the QSO and galaxy. Figure 1 shows the distribution of \( z_{\text{eff}} \) and \( z_{\text{qso}} \) for the 1647 pairs, with the location of the predicted periodic peaks indicated. No periodicity leaps off the page, but since the effect is likely to be quite subtle, one would not necessarily expect to be able to pick it out from the raw data, so it is important to carry out a rigorous statistical analysis.

4 ANALYSIS

4.1 The Power Spectrum

We wish to measure the power spectrum for a set of \( N \) measurements of some quantity \( x_i \) [in the current case, the value of \( \log(1 + z_{\text{eff}}) \) for different QSO-galaxy pairs]. Following the conventions of Burbidge & Napier (2001), we define the power \( I \) at period \( P \) via the formulae

\[
I(P) = 2R^2 / \sum_{i=1}^{N} w_i^2
\]  (2)

where

\[
R^2 = S^2 + C^2
\]  (3)

with

\[
S = \sum_{i=1}^{N} w_i \sin(2\pi x_i/P), \quad C = \sum_{i=1}^{N} w_i \cos(2\pi x_i/P).
\]  (4)

The quantity \( w_i \) is a weighting function to apodize any ill effects from the window function (see below); in the Burbidge & Napier (2001) analysis, \( w_i \equiv 1 \). With this definition of the power spectrum, an infinite uniform random distribution of values \( x_i \) would yield \( I \equiv 2 \).

Error bars on \( I(P) \) can be estimated using the “jackknife” technique (Efron 1979) of drawing all possible samples of \( N - 1 \) values from the \( N \) data points (without replacement), repeating the power spectral analysis on these resamplings, and calculating the standard deviation in the derived values of \( I \) at different periods \( P \), \( \sigma_J(P) \). The best estimator for the standard error in the value of \( I \) is then just \( \sqrt{N - 1} \sigma_J \).
4.2 The Window Function

The above analysis works perfectly for detecting periodic signals in data sets of infinite extent. However, in practice, such analyses are based on data sets that are finite in extent. In particular, the redshift distribution of QSOs has a cut-off at low redshifts due to the small volume sampled, and one at high redshift due to the colour selection by which QSOs are found. In addition, there may well be variations in average numbers due to evolution in the quasar population with redshift. Thus, the idealized infinite data series is truncated to a finite series by a “window function”, which varies from a value of unity where no data are missed to zero outside the range sampled.

This truncation can introduce strong spurious features into the power spectrum. Its impact depends quite sensitively on how sharply the cut-off occurs. As an extreme example, the upper panel of Fig. 2 shows a simulation of a uniform random distribution truncated sharply at 0 and 0.7, corresponding crudely to the distribution in log(1+z) of the data presented in Burbidge & Napier (2001). As can be seen from this figure, the window function introduces many seemingly-periodic features, so that the resultant spectrum differs greatly from the $I \equiv 2$ that one would expect for an infinite uniform distribution. This figure also shows that the jackknife error analysis does a good job in determining the true root-mean-square uncertainty in the power spectrum.

In practice, the window function is unlikely to cut off this sharply, so the effects will be rather smaller than this extreme case. Nonetheless, particularly for relatively small periodic signals, it is vital that the effects of the window function be taken into account [a point, indeed, noted by Burbidge & Napier (2001) in their analysis of Karlsson’s (1990) data, where one peak is disregarded as just such an artifact]. However, with relatively small samples taken from heterogeneous data sets, it is very difficult to formally quantify the selection function that specifies the shape of the window, so a rigorous analysis is difficult to implement.

Fortunately, without knowing the exact nature of the window function of the sample, one can manipulate the data in order to specify ones own more optimal window – a procedure that statisticians whimsically refer to as “carpentry.” This process involves reducing the weighting of data close to the ends of the range observed, thereby smoothing off the sharp edges of the window, or “apodizing” the function. We achieve this apodization by using the Hann function as a weighting,

$$w_i = \frac{1}{2} \left[ 1 - \cos \left( \frac{2\pi x_i}{L} \right) \right]$$

in equation (5). Here, $L$ is chosen to cover the range over which the data are selected, so that the weighting goes smoothly from unity in the middle of the range to zero at $x_i = 0$ and $x_i = L$. As the lower panel of Figure 2 shows, even for the most extreme possibility of an intrinsically instantaneous cut-off in the window function, this procedure effectively restores the power spectrum to close to the expected value of $I(P) \equiv 2$, without compromising the errors derived using the jackknife analysis.

One concern with such a process is that it could erase real periodic signals as well as the spurious artifacts. To address this issue, we repeated the above simulation with a small periodic addition to the uniform distribution. As Figure 3 shows, the apodization of the data does not erase the periodic signal, and, once again, the jackknife errors provide a good estimate for the true uncertainty.
5 RESULTS

5.1 The Karlsson data set

As an initial test of the code developed for this study, we have reanalysed the 116 QSO redshifts from Karlsson (1990) to make sure that we can reproduce the results derived in Burbidge & Napier (2001). As Figure 4 shows, the unweighted spectral analysis reveals the peak in the spectrum at $P \sim 0.09$ that Burbidge & Napier (2001) detected, as well as the peak at $P \sim 0.07$ that they attributed to the window function. As expected for this latter artifact, when the data are apodized, its strength is reduced to an insignificantly $\sim 1\sigma$ above the noise value of $I = 2$. However, the stronger “real” signal is even more dramatically reduced to a significance of only $\sim 1\sigma$. This analysis would indicate that the peak at $P \sim 0.09$ may well be compromised by the window function in this data set.

5.2 The 2dF data set

Figure 5 shows the same analysis applied to the sample of 1647 QSO–galaxy pairs drawn from the 2dF surveys, as described in Section 3. Here, the raw and apodized power spectra are quite similar – the apodization’s lack of major impact presumably reflects the overall smooth distribution in Fig. 4, which is already quite close to optimal in shape. In any case, it is apparent that there is no significant periodicity in the data at $P \sim 0.09$, or, indeed, at any other frequency. An analysis of the QSOs’ heliocentric redshifts revealed a similar absence of significant periodicities. Given that there are almost eight times as many data points in this sample as in the previous analysis by Burbidge & Napier (2001), we must conclude that the previous detection of a periodic signal arose from the combination of noise and the effects of the window function.

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