Mon. Not. R. Astron. Soc. **342,** L9–L13 (2003)

Ghosts of the Milky Way: a search for topology in new quasar catalogues

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Accepted 2003 April 3. Received 2003 March 26; in original form 2003 February 27

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ABSTRACT

We revisit the possibility that we inhabit a compact multi-connected flat, or nearly flat, Universe. Analysis of *COBE* data has shown that, for such a case, the size of the fundamental domain must be a substantial fraction of the horizon size. Nevertheless, there could be several copies of the Universe within the horizon. If the Milky Way was once a quasar we might detect its 'ghost' images. Using new large quasar catalogues we repeat the search by Fagundes & Wichoski for antipodal quasar pairs. By applying linear theory to account for the peculiar velocity of the Local Group, we are able to narrow the search radius to 134 arcsec. We find seven candidate antipodal quasar pairs within this search radius. However, a similar number would be expected by chance. We argue that, even with larger quasar catalogues, and more accurate values of the cosmological parameters, it is unlikely to be possible to identify putative ghost pairs unambiguously, because of the uncertainty of the correction for peculiar motion of the Milky Way.

Key words: quasars: general – cosmology: observations – large-scale structure of Universe.

1 INTRODUCTION

The idea that we inhabit a compact multi-connected Universe has been presented by many authors (see review by Lachièze-Rey & Luminet 1995). The simplest such Universe is one in which space is flat and may be visualized as tiled by a 'fundamental parallelepiped' with lengths $\alpha_x, \alpha_y, \alpha_z$. If the sides of the fundamental domain were significantly smaller than the horizon length, $R_{\rm H}$, observable effects would be present. One of the most interesting, albeit surreal, effects would be the appearance of 'ghost images'. This is where radiation from an object, such as a galaxy, has traversed the fundamental domain, resulting in a repeat or ghost image of the object. The simplest ghost images to search for are ones of our own Galaxy, since they appear at the nodes of a lattice of which the Milky Way is the origin. Therefore ghost images might be most simply identified by searching for antipodal pairs. In this paper we merge three new large quasar catalogues to search for ghost images of the Milky Way.

The best limits on the size of the fundamental domain come from analyses of the *COBE* measurement of the cosmic microwave background. The simplest space is the hypertorus. This is a spatially flat topology where opposite faces of the parallelepiped are identified. There are three other compact spaces, involving twists of $\pi/2$ or π in pairing opposite faces of a parallelepiped (e.g. Levin, Scannapieco & Silk 1998). There are also two compact models in which the fundamental polyhedron is a hexagonal prism with twists of $\pi/3$ and $2\pi/3$ (Lachièze-Rey & Luminet 1995). For equal sides of the parallelepiped, Levin et al. (1998) obtained a minimum size of the side of the fundamental domain of $0.8R_{\rm H}$, and a similar result for the hexagonal prism. Bond, Pogosyan & Souradeep (2000) obtained a somewhat larger limit for the hypertorus. For unequal sides the constraints are less strong, and there remains the possibility that there are many copies of the Universe within the horizon. The existence of antipodal pairs is a common feature of most topologies whether the geometry is hyperbolic, flat or spherical. To this extent, therefore, although we assume a flat geometry our analysis is also relevant to nearly flat geometries.

On the basis of these *COBE* limits, it is clear that any search for ghosts needs to use objects at large redshifts, and so catalogues of quasars are an obvious source. Many authors have used quasars to probe topological structure (Fagundes & Wichoski 1987; Fagundes 1989; Roukema 1996), but have yet to constrain topology using these methods. Following the suggestion that many large galaxies go through a quasar phase, Fagundes & Wichoski (1987) searched a quasar catalogue for antipodal quasar pairs in the hope of finding ghost images of the Milky Way. In fact, even with complete

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catalogues of quasars over the whole sky, good fortune would be required for success with such a search. This is because quasar lifetimes must be short relative to the age of the Universe, so the method relies on the quasar being alive at the particular time corresponding to the look-back time of any copies. Nevertheless, quasar catalogues have grown enormously in the last few years, owing in particular to the contributions of the 2-degree Field (hereafter 2dF) QSO survey and the Sloan Digital Sky Survey (hereafter SDSS). Therefore we considered it timely to repeat the search of Fagundes & Wichoski (1987) for antipodal quasar pairs.

The outline of the paper is as follows. In Section 2 we describe the quasar catalogues used. In Section 3 we explain the search method. The search is complicated by the peculiar velocity of the Milky Way, v_0, which displaces the ghost images from opposition by order v_0/c, and so must be accounted for. A suitable search radius, then, depends on the uncertainty of the historical motion of the Milky Way, which depends, in turn, on the uncertainty of the cosmological density parameter. The results of the search are presented in Section 4, together with a brief discussion. We assume flat universal geometry ($\Omega_{\mathrm{m}} + \Omega_\Lambda = 1$) throughout and consider only topologies without axial twists.

2 QUASAR CATALOGUES

The quasar catalogue used for this investigation was compiled from three sources.

(i) The complete candidate list for the 2dF QSO survey (Smith et al., in preparation). This catalogue contains 47 768 objects, from which we extracted the 23 340 quasars with spectroscopic redshifts. A subset of 10 000 of the quasars has been published by Croom et al. (2001).

(ii) The early data release from the SDSS Quasar Catalogue (Schneider et al. 2002) which contains 3814 quasars.

(iii) The quasar catalogue of Véron-Cetty & Véron (2001)[1] which contains 23 760 quasars.

Duplicate quasars, primarily the 10 000 quasars in Croom et al. (2001) which are included in the Véron-Cetty & Véron catalogue, need to be eliminated. We searched the merged list for pairs of objects within 2 arcsec and $\Delta z < 0.02$, and in each case eliminated one of the pair. This could, in fact, have included real pairs, but this would not affect our search for antipodal pairs, since it uses a much larger search radius. This left a final catalogue of 43 271 objects reaching a maximum redshift of $z = 5.8$. The sky distribution of the quasars in this merged catalogue is illustrated in Fig. 1.

3 METHOD

3.1 Peculiar velocity

Because of the past motion of the Local Group, ghost images of the Milky Way will appear displaced from the lattice nodes. This angular displacement is of the order of $v_0/c \sim 7$ arcmin, and must be corrected for. The effect is greatest for objects lying perpendicular to the direction of Local Group motion, and falls to zero for objects that lie on the path of Local Group motion. Therefore the idea is to apply an appropriate angular correction for each object in our catalogue to bring true antipodal ghost images into opposition. The uncertainty of the computed correction sets the search radius, since it is much greater than the uncertainty of the quasar coordinates, or any other relevant effect. Previous searches for antipodal quasar pairs have failed to correct for the motion of the Local Group.

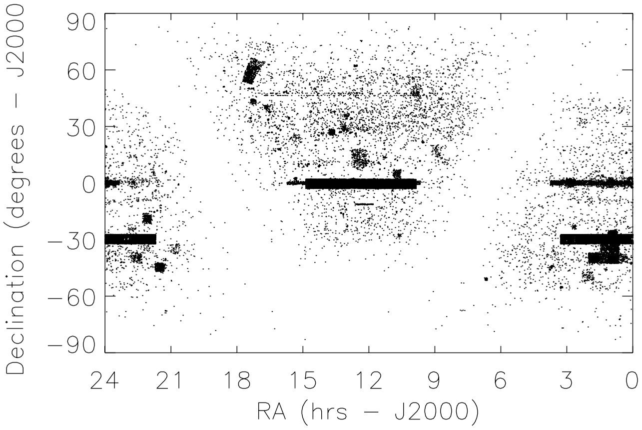

Figure 1. Sky distribution of the 43 271 quasars in the merged catalogue used for the search.

To find this angular correction we turn to linear theory for an expression for peculiar velocity. From this we can find the comoving distance moved by the Local Group as a function of redshift, and from this compute the appropriate angular correction for each quasar.

The peculiar velocity, v_{pec}, is related to the peculiar acceleration, $\boldsymbol{g}$, by

$$\boldsymbol{v}_{\mathrm{pec}} = \frac{a(z)}{a(0)}\dot{\boldsymbol{x}} = \frac{2f}{3\Omega H}\boldsymbol{g}$$

(Peebles 1993), where $a(z)$ is the scale factor at epoch z and $\dot{\boldsymbol{x}}$ is a comoving velocity. Here

$$\Omega = \Omega_{\mathrm{m}}\left(\frac{H}{H_0}\right)^{-2}(1+z)^3.$$

The term f is the dimensionless velocity factor, given by

$$f = \frac{\mathrm{d}\log\delta}{\mathrm{d}\log a},$$

where δ is the overdensity or density contrast. For a flat universe, a good approximation to f is given by

$$f = \Omega^{0.6} + \frac{1}{70}\left[1 - \frac{1}{2}\Omega(1+\Omega)\right]$$

(Lahav et al. 1991).

In our linear approximation the peculiar acceleration is given by

$$\boldsymbol{g} = \frac{GM_{\mathrm{p}}(\boldsymbol{x}_{\mathrm{p}} - \boldsymbol{x}_{\mathrm{lg}})}{a^2|\boldsymbol{x}_{\mathrm{p}} - \boldsymbol{x}_{\mathrm{lg}}|^3},$$

where $\boldsymbol{x}$ is a comoving distance and the subscripts refer to a single point-attractor, p, and the Local Group, lg. This equation provides the scaling of $\boldsymbol{g}$ with a, but the mass of the attractor and its distance are not needed explicitly, since we have a measurement of the peculiar velocity today.

The expression for peculiar velocity is numerically integrated to find the comoving distance moved by the Local Group as a function of redshift. This is then converted to an angular correction for a ghost image at redshift z. The only input variables to this correction algorithm are Ω_{m} and $\boldsymbol{v}_0$. The values adopted for this analysis are:

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[1] Available at http://www.obs-hp.fr/www/catalogues/veron2_10/veron2_10.html.

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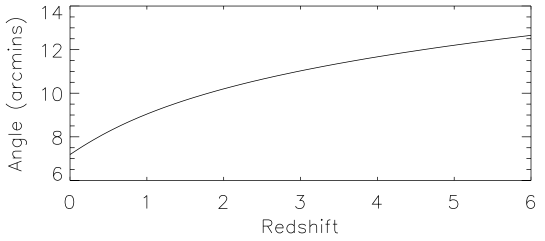

Figure 2. The angular correction to the quasar position as a function of redshift, for a quasar located in a direction perpendicular to the direction of Local Group motion (maximum correction).

(i) $\Omega_{\mathrm{m}} = 0.3 \pm 0.1$ (e.g. Verde et al. 2002);

(ii) $v_0 = 627 \pm 22$ km s^{-1} in direction $(l, b) = (276^{\circ} \pm 3^{\circ}, 30^{\circ} \pm 3^{\circ})$ from *COBE* data (Kogut et al. 1993).

The angular correction for each object depends on redshift and the angle between the quasar, the observer and the direction of Local Group motion. For an object located perpendicular to the direction of Local Group motion (maximum correction) this correction is approximately 7 arcmin at $z = 0$, and increases to approximately 12 arcmin at $z = 5$. A plot of this angular correction is shown in Fig. 2.

3.2 Search radius

An appropriate search radius must be related to the uncertainties in the input data, and also involves a trade-off between contamination and incompleteness. Too large a tolerance and we recover too many false positives, swamping any real pairs, while with too small a tolerance we risk losing the few putative real pairs in the data.

We required that the redshifts of the pair agree within a tolerance $\Delta z = 0.04$. The large majority of the redshifts in the catalogue have been measured from intermediate-resolution spectra, many by cross-correlation against a template spectrum. For these the accuracy of the redshift is better than $\Delta z = 0.01$ (e.g. Croom et al. 2001). Therefore the chosen tolerance will include nearly all real pairs in the catalogue.

The position of any quasar in the catalogue, after correction for the peculiar velocity of the Local Group, is uncertain, because of the uncertainty of the parameters Ω_{m} and v_0. Gravitational lensing could also contribute, since the light-paths from antipodal quasars traverse different regions of the fundamental domain. This is a much smaller source of uncertainty, however, and may be neglected. It would be very unlikely for a ghost pair to be lensed out of opposition by more than a few arcsec.

In principle we could compute a probability distribution function (pdf) for the coordinates of each quasar, and select a contour level at, say, the 95 per cent confidence level. Then, in searching for an antipodal quasar, the size of the contour should be doubled. This is because the error in the peculiar velocity correction (due to poor choice of Ω_{m}, v_0) is identical for each quasar of an antipodal pair. This procedure would be computationally expensive, and we followed a simpler Monte Carlo approach. The algorithm to correct the coordinates was run on the catalogue 200 times, each time using values of the input parameters Ω_{m}, v_0 chosen from a Gaussian distribution about their mean. We computed the angular displacement from the mean position for each quasar in every simulation, and selected the angle that included 95 per cent of all the points. This angle was 67 arcsec. Therefore the procedure for the search was to correct the quasar coordinates using the best estimates for Ω_{m} and v_0, and then for each quasar to search for antipodal quasars in the catalogue within a search angular radius of 134 arcsec. Because the coordinate pdfs for each quasar differ in size, shape and orientation, in some cases this search radius will be unnecessarily large, and in some cases too small. By construction, however, it will include 95 per cent of any real antipodal pairs.

We found that the largest source of error is from the uncertainties in our current knowledge of the speed and direction of the Local Group relative to the cosmic microwave background. Our motion *within* the Local Group is a source of error unaccounted for in our search radius determination. As we are searching for a ghost of the Galaxy rather than a ghost of the Local Group, our motion within it should be considered. However, this motion is small compared with the large-scale streaming motion of the Local Group itself.

4 RESULTS AND DISCUSSION

With a search radius of 134 arcsec and $\Delta z = 0.04$ we recover seven antipodal quasars pairs. Details of the pairs are provided in Table 1. The table includes the coordinates of each quasar in the pair both before and after correction for peculiar velocity, as well as the

Table 1. Antipodal pairs of quasars within 134 arcsec and $\Delta z = 0.04$. Redshifts preceded by ‡ are of lesser accuracy or even wrong (see Véron-Cetty & Véron catalogue for further details and naming convention).

Name	Position (J2000) RA	Dec.	Corrected position RA	Dec.	Redshift	Magnitude	Catalogue	Deviation from opposition
∗Q 0007+0236	$00^{\mathrm{h}}10^{\mathrm{m}}19^{\mathrm{s}}.5$	$+02^{\circ}53''\ 38'$	$00^{\mathrm{h}}10^{\mathrm{m}}23^{\mathrm{s}}.1$	$+02^{\circ}49'57''.5$	0.588	$V = 18.4$	Véron	$\theta = 99$ arcsec
2QZJ121030.8-024456	$12^{\mathrm{h}}10^{\mathrm{m}}30^{\mathrm{s}}.88$	$-02^{\circ}44'56''.3$	$12^{\mathrm{h}}10^{\mathrm{m}}27^{\mathrm{s}}.2$	$-02^{\circ}48'39''.7$	0.6257	$b_{\mathrm{j}} = 20.1$	2dF	$\Delta z = 0.0377$
∗Q 0058−3424	$01^{\mathrm{h}}01^{\mathrm{m}}14^{\mathrm{s}}.1$	$-34^{\circ}08'31''$	$01^{\mathrm{h}}01^{\mathrm{m}}34^{\mathrm{s}}.7$	$-34^{\circ}16'58''.0$	‡2.08	$V = 19.36$	Véron	$\theta = 129$ arcsec
∗KP 1259.4+34.7	$13^{\mathrm{h}}01^{\mathrm{m}}46^{\mathrm{s}}.5$	$+34^{\circ}26''\ 34'$	$13^{\mathrm{h}}01^{\mathrm{m}}25^{\mathrm{s}}.8$	$+34^{\circ}18'06''.0$	‡2.08	$V = 18.5$	Véron	$\Delta z = 0.0000$
FIRST J1057+3119	$10^{\mathrm{h}}57^{\mathrm{m}}5^{\mathrm{s}}.2$	$+31^{\circ}19'07''$	$10^{\mathrm{h}}57^{\mathrm{m}}06^{\mathrm{s}}.7$	$+31^{\circ}11'01''.5$	1.332	$V = 18.7$	Véron	$\theta = 27$ arcsec
2QZJ225706.5−310312	$22^{\mathrm{h}}57^{\mathrm{m}}6^{\mathrm{s}}.56$	$-31^{\circ}03'12''.5$	$22^{\mathrm{h}}57^{\mathrm{m}}05^{\mathrm{s}}.0$	$-31^{\circ}11'17''.2$	1.3398	$b_{\mathrm{j}} = 20.1$	2dF	$\Delta z = 0.0078$
∗QNY1:11	$12^{\mathrm{h}}36^{\mathrm{m}}9^{\mathrm{s}}.9$	$-00^{\circ}48'03''$	$12^{\mathrm{h}}36^{\mathrm{m}}02^{\mathrm{s}}.8$	$-00^{\circ}52'56''.0$	1.874	$V = 21.3$	Véron	$\theta = 60$ arcsec
003551.98+005726.3	$00^{\mathrm{h}}35^{\mathrm{m}}51^{\mathrm{s}}.98$	$+00^{\circ}57'26''.3$	$00^{\mathrm{h}}35^{\mathrm{m}}59^{\mathrm{s}}.0$	$+00^{\circ}52'33''.9$	1.905	$g' = 19.06$	SDSS	$\Delta z = 0.0310$
∗2240.0+0019	$22^{\mathrm{h}}42^{\mathrm{m}}33^{\mathrm{s}}.3$	$+00^{\circ}27''\ 09'$	$22^{\mathrm{h}}42^{\mathrm{m}}31^{\mathrm{s}}.6$	$+00^{\circ}22'30''.3$	‡2.0	$V = 20.0$	Véron	$\theta = 95$ arcsec
2QZJ104229.5-001616	$10^{\mathrm{h}}42^{\mathrm{m}}29^{\mathrm{s}}.53$	$-00^{\circ}16'16''.1$	$10^{\mathrm{h}}42^{\mathrm{m}}31^{\mathrm{s}}.3$	$-00^{\circ}20'55''.7$	1.9713	$b_{\mathrm{j}} = 19.7$	2dF	$\Delta z = 0.0287$
2QZJ133904.3−001945	$13^{\mathrm{h}}39^{\mathrm{m}}4^{\mathrm{s}}.35$	$-00^{\circ}19'45''$	$13^{\mathrm{h}}38^{\mathrm{m}}50^{\mathrm{s}}.6$	$-00^{\circ}24'44''.3$	1.3474	$b_{\mathrm{j}} = 20.4$	2dF	$\theta = 84$ arcsec
013837.29+002818.5	$01^{\mathrm{h}}38^{\mathrm{m}}37^{\mathrm{s}}.29$	$+00^{\circ}28'18''.5$	$01^{\mathrm{h}}38^{\mathrm{m}}50^{\mathrm{s}}.9$	$+00^{\circ}23'20''.2$	1.35	$g' = 18.93$	SDSS	$\Delta z = 0.0026$
2QZJ112525.9−010342	$11^{\mathrm{h}}25^{\mathrm{m}}25^{\mathrm{s}}.95$	$-01^{\circ}03'42.4''$	$11^{\mathrm{h}}25^{\mathrm{m}}24^{\mathrm{s}}.7$	$-01^{\circ}08'07''.6$	1.743	$b_{\mathrm{j}} = 20.4$	2dF	$\theta = 74$ arcsec
232519.33+011147.8	$23^{\mathrm{h}}25^{\mathrm{m}}19^{\mathrm{s}}.33$	$+01^{\circ}11'47''.8$	$23^{\mathrm{h}}25^{\mathrm{m}}20^{\mathrm{s}}.6$	$+01^{\circ}07'24''.4$	1.724	$g' = 18.45$	SDSS	$\Delta z = 0.0190$

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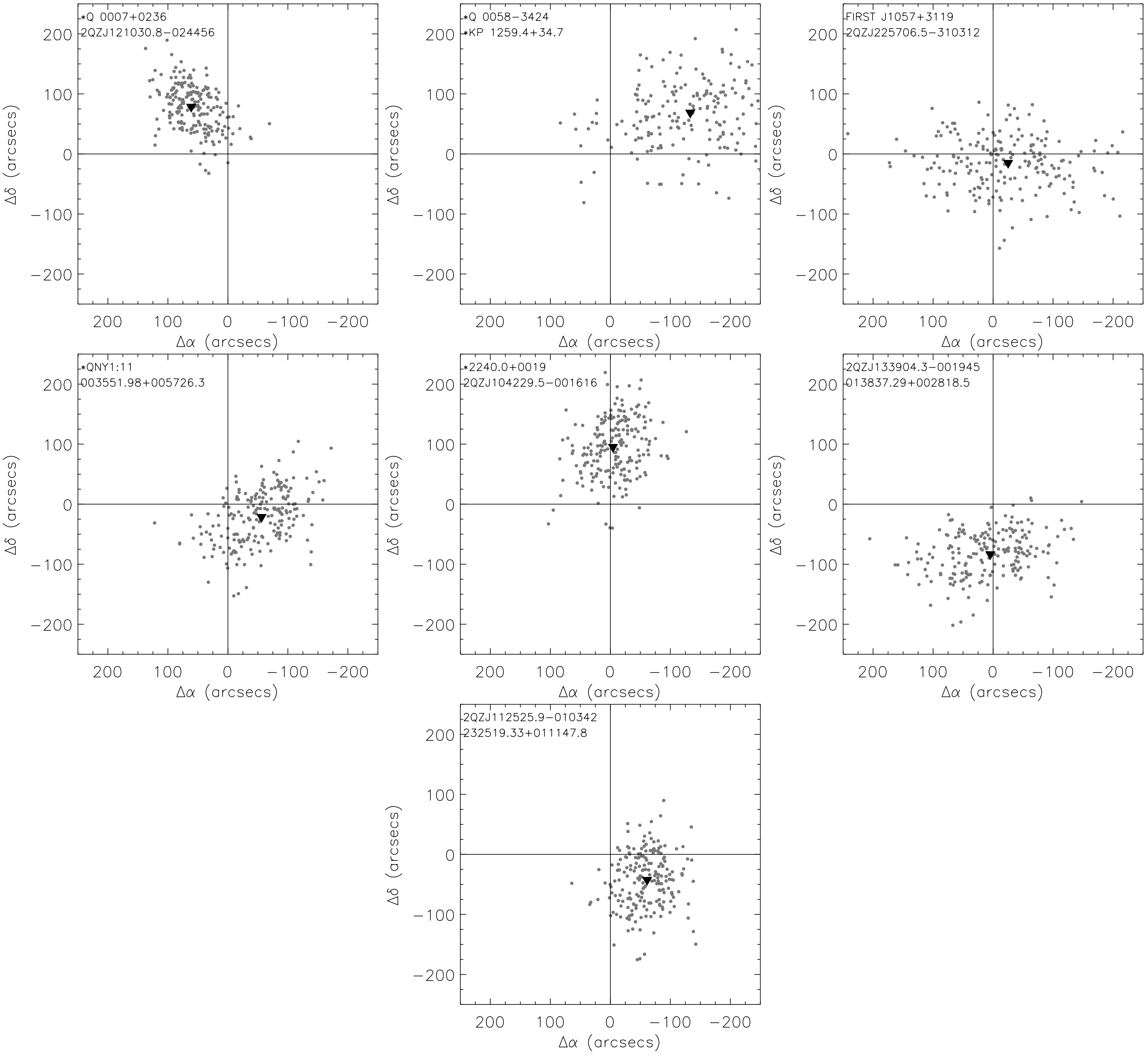

Figure 3. Plots of the seven candidate ghost pairs indicating the degree of anti-alignment, and its variation with the input parameters. For each pair the axes are centred on the antipode of the first quasar, and the triangle marks the displacement of the second quasar for the best values of the parameters Ω_m and v_0. In each case the second quasar lies within the search radius of 134 arcsec, which is how they were selected. The points show the computed displacements for the Monte Carlo variations of the parameters Ω_m and v_0. This distribution overlaps the antipode in each case, indicating that for possible values of the parameters Ω_m and v_0 the two quasars could be perfectly anti-aligned.

redshifts, the brightnesses, the catalogue containing the quasar, the redshift difference and the angular displacement from opposition of each pair.

The relative positions of the two quasars in each pair are plotted in Fig. 3. For each pair the plot is centred on the antipode of the first quasar in the pair, and the points illustrate the offset of the second quasar from perfect anti-alignment, for the 200 Monte Carlo realizations of the parameters Ω_m and v_0. In each case the distribution of points overlaps perfect anti-alignment, indicating that, given the uncertainties in the parameters, the pairs could be real ghost images. As a further investigation, the angles between the axes of each quasar pair were computed to search for any specific angles that could indicate points on a lattice (such as $\pi/2$), but nothing striking was discovered. There are magnitude differences, up to $\Delta m = 2$, between the two quasars of a pair, but these might be due to variability because of the epoch differences of the observations, or time delay differences because the light-paths to us traverse different regions of space, or the differences could be because each quasar is being viewed from a different direction. For the same reasons it would not be unreasonable for the spectra to differ also. A more important consideration is the number of pairs that might be expected by chance.

We investigated how the expected number of antipodal pairs varied with respect to the search tolerance. We varied the search angular

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radius from $\Theta = 0$ to 10 arcmin, and the redshift tolerance from $\Delta z =$ 0 to 0.4. Although the catalogue is inhomogeneous, we found that the number of antipodal quasar pairs recovered followed closely the relations $\propto\Theta^2$ and $\propto\Delta z$ expected for unrelated pairs. Therefore we used a fit to the relations at large Θ, Δz to establish an estimate of the number of pairs expected by chance. For our search tolerance of $\Theta = 134$ arcsec we would have expected 12 ± 3.5 quasar pairs by chance. Our result of seven pairs, therefore, is consistent with chance. While it remains possible that one or more of the pairs could be a real ghost pair, this cannot be proven from the existing data.

4.1 Discussion

We have presented a search for ghost images of our Galaxy using the method of antipodal quasar pair detection, correcting for the angular distortion arising from the history of motion of the Local Group. We have found no significant difference in the number of pairs found over the number that we would expect purely by chance using our search tolerance on this catalogue. We have examined the angles between the axes of each quasar pair but failed to discover any indication of a lattice structure.

The uncertainties both with our present knowledge of cosmological parameters and with the peculiar velocity of the Local Group make a search such as this increasingly difficult as quasar catalogues increase in size. To prove significance in a search such as this, the search tolerance needs to be reduced to a value where we would be expecting only one or two detections purely by chance. In the future we can expect improvements in the accuracy of the parameters Ω_m and v_0 that will allow a smaller search radius, which could compensate for the much larger future quasar catalogues. However, soon the uncertain correction for the peculiar motion of the Milky Way within the Local Group will become a significant factor. Given the *COBE* constraints on the size of the fundamental domain (and so the small possible number of ghost images), and the relatively short lifetime of quasars, it would seem unlikely that it will be possible to identify putative ghost images, unambiguously, by this method. Instead, extension of the search to configurations of three or more quasars on a lattice could yield a convincing detection.

ACKNOWLEDGMENTS

We are grateful to Andrew Jaffe, Thomas Babbedge, Matthew Pieri and Matthew Fox for their helpful comments. The 2dF QSO Redshift Survey (2QZ) was compiled by the 2QZ survey team from observations made with the 2-degree Field on the Anglo-Australian Telescope. Funding for the creation and distribution of the SDSS Archive has been provided by the Alfred P. Sloan Foundation, the Participating Institutions, NASA, NSF, the US Department of Energy, the Japanese Monbukagakusho, and the Max Planck Society. The SDSS website is http://www.sdss.org.

REFERENCES

Bond J. R., Pogosyan D., Souradeep T., 2000, Phys. Rev. D, 62, 043006

Croom S. M., Smith R. J., Boyle B. J., Shanks T., Loaring N. S., Miller L., Lewis I. J., 2001, MNRAS, 322, L29

Fagundes H. V., 1989, ApJ, 338, 618

Fagundes H. V., Wichoski U. F., 1987, ApJ, 322, L5

Kogut A. et al., 1993, ApJ, 419, 1

Lachièze-Rey M., Luminet J.-P., 1995, Phys. Rep., 254, 135

Lahav O., Lilje P. B., Primack J. R., Rees M. J., 1991, MNRAS, 251, 128

Levin J., Scannapieco E., Silk J., 1998, Phys. Rev. D, 58, 103516

Peebles P. J. E., 1993, Principles of Physical Cosmology. Princeton Univ. Press, Princeton, NJ

Roukema B. F., 1996, MNRAS, 283, 1147

Schneider D. P. et al., 2002, AJ, 123, 567

Verde L. et al., 2002, MNRAS, 335, 432

Véron-Cetty M.-P., Véron P., 2001, A Catalogue of Quasars and Active Nuclei, 10th edn. Observatoire de Haute Provence

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