The AMIGA sample of isolated galaxies

IV. A catalogue of neighbours around isolated galaxies

S. Verley1,2,3, S. C. Odewahn4, L. Verdes-Montenegro2, S. Leon5,2, F. Combes1, J. Sulentic6, G. Bergond2, D. Espada2, E. García2, U. Lisenfeld7, and J. Sabater2

1 LERMA – Observatoire de Paris, 61, avenue de l’Observatoire, 75014 Paris, France
e-mail: Simon.Verley, Françoise.Combes@obspm.fr
2 Instituto de Astrofísica de Andalucía – CSIC, C/ Camino Bajo de Huétor, 50, 18008 Granada, Spain
e-mail: simon, lourdes, jsm, giltes, daniel, garcia@iaa.es
3 INAF – Osservatorio Astrofisico di Arcetri, Largo E. Fermi, 51-50125 Firenze, Italy
e-mail: simon@arcetri.astro.it
4 McDonald Observatory, University of Texas, USA
e-mail: sco@astro.as.utexas.edu
5 Instituto de RadioAstronomía Milimétrica, Avenida Divina Pastora, 7, Núcleo Central, E 18012 Granada, Spain
e-mail: leon@iram.es
6 Department of Astronomy, University of Alabama, Tuscaloosa, USA
e-mail: giacomo@merlot.astr.ua.edu
7 Departamento de Física Teórica y del Cosmos, Facultad de Ciencias, Universidad de Granada, Spain
e-mail: ute@ugr.es

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ABSTRACT

Context. Studies of the effects of environment on galaxy properties and evolution require well defined control samples. Such isolated galaxy samples have up to now been small or poorly defined. The AMIGA project (Analysis of the interstellar Medium of Isolated Galaxies) represents an attempt to define a statistically useful sample of the most isolated galaxies in the local ($z\leq0.05$) Universe.

Aims. A suitable large sample for the AMIGA project already exists, the Catalogue of Isolated Galaxies (CIG, Karachentseva 1973; 1050 galaxies), and we use this sample as a starting point to refine and perform a better quantification of its isolation properties.

Methods. Digitised POSS-I E images were analysed out to a minimum projected radius $R=1050$ galaxies), and we use this sample as a starting point to refine and perform a better quantification of its isolation properties.

Results. Six hundred sixty-six galaxies pass and two hundred eighty-four fail the original CIG isolation criterion. The available redshift data confirm that our catalogue involves a largely background population rather than physically associated neighbours. We find that the exclusion of neighbours within a factor of four in size around each CIG galaxy, employed in the original isolation criterion, corresponds to $\Delta r \approx 18000$ km s$^{-1}$ indicating that it was a conservative limit.

Conclusions. Galaxies in the CIG have been found to show different degrees of isolation. We conclude that a quantitative measure of this is mandatory. It will be the subject of future work based on the catalogue of neighbours obtained here.

Key words. galaxies: general – galaxies: fundamental parameters – galaxies: formation – galaxies: evolution

1. Introduction

During the past 30 years it has become clear that galaxy properties (e.g. morphology, star formation, nuclear activity) and evolution may be driven as strongly by environment as by initial conditions. The role of environmental conditions is not yet fully quantified for at least two reasons: 1) confusion about the definition of “environment” and 2) lack of control samples of galaxies. This is mandatory. It will be the subject of future work based on the catalogue of neighbours obtained here.

Effects related to local galaxy surface density can be especially difficult to quantify because automated sample selection can often miss these close neighbours. Ideally we seek a statistically useful sample of galaxies that has been carefully cleaned of: a) close neighbours and that reside in b) the lowest galaxy surface density regions of the local Universe. In order to be statistically useful the sample must be large enough to allow us to assess environmental effects both as a function of morphological type and luminosity. The motivation of the AMIGA (Analysis of the Interstellar Medium of Isolated Galaxies) project is to identify such a sample of isolated galaxies.

The AMIGA project adopted the Catalogue of Isolated Galaxies (CIG: Karachentseva 1973) as a starting point. The sample is mandatory. It will be the subject of future work based on the catalogue of neighbours obtained here.
of the CIG mentioned above it is not surprising that the full sample because it obviously lacked global homogeneity (Karachentsev 1972) in a companion survey to the CIG. This illustrates the danger inherent in compiling 2D (or 3D) catalogue (Turner & Gott 1975, Balkowski & Chamauraux 1981). Haynes & Giovanelli (1983) showed that likewise most of the isolated galaxies are outer components of groups or clusters.

Hence, it seems difficult to find a truly isolated population of galaxies, but instead one can have access to regions of very low galaxy density, where the galaxies reflect properties characterising their formation. However, during the past 30 years, a variety of widely different criteria has been used when defining isolation (magnitude limited samples, redshift information used or not, distance to the nearest galaxies different from one definition to the other, etc.), as shown by the abundant literature: Turner & Gott (1975), Balkowski & Chamauraux (1981), Vettolani et al. (1986), Zaritsky et al. (1993), Aars et al. (2001), Colbert et al. (2001), Pisano et al. (2002), Prada et al. (2003), Márquez & Moles (1996, 1999), Márquez et al. (2002, 2003), Varelà et al. (2004). Most of these studies only sample ten to approximately two hundred galaxies, which is not sufficient for statistical analysis.

Studies with independent isolated samples usually involve small numbers and show a surprisingly small overlap with the CIG (e.g., Xanthopoulos & de Robertis 1991, Márquez & Moles 1996, 1999, Morgan et al. 1998, Aguerri 1999, Pisano & Wilcots 1999, Colbert et al. 2001, Korneiichuk et al. 2001, Pisano et al. 2002, Madore et al. 2004, Reda et al. 2004). In a few cases the samples include southern objects that lie outside the CIG sky coverage. Many of them, surprisingly, contain more overlap with catalogues of pairs or triplets than with the CIG. This usually involves computer-based compilations from a magnitude limited (2D or 3D) catalogue (Turner & Gott 1975, Vettolani et al. 1986). If one of the galaxies in a pair falls below the magnitude limit of the catalogue then the pair will be adopted as an isolated single galaxy more readily than a CIG member. The pair isolation criterion is more stringent if isolation is defined in terms of pair separation rather than a component galaxy diameter. Visual confirmation of isolation is essential and is one of the strengths of the CIG. This list is not intended to argue about the relative merits of different isolated galaxy selection criteria. It is intended to show: 1) the lack of consensus about what constitutes a reasonable isolated galaxy or isolated galaxy sample, 2) how difficult
it can be to compare different results for different selected isolated samples and 3) the confusion about selection on the basis of nearest neighbour vs. selection on the basis of local surface density.

Most galaxies in other samples that are found north of \( \delta = -3^\circ \), and are missing from the CIG, reflect violation of the CIG isolation criterion rather than having been overlooked during the CIG compilation. The CIG isolation criterion is more stringent than most others that have been used. One of the goals of the AMIGA project is to extract from the CIG a significant subsample of the most isolated galaxies which must represent the low density tail of galaxy population in the local Universe. The remainder of the sample will involve degrees of lesser isolation where effects of environment might begin to be detected. One of our goals is to detect that threshold.

### 3. The Catalogue of Isolated Galaxies

#### 3.1. Definition

The catalogue is composed of 1051 objects with apparent Zwicky magnitude \( m_{\text{zw}} \) brighter than 15.7 and declination \( \beta > -3^\circ \). Karachentseva visually inspected the Palomar Sky Survey prints, trying to identify those galaxies in the Catalogue of Galaxies and Clusters of Galaxies (CGCG, Zwicky et al. 1968) which have no near similar size neighbours. Primary galaxies with angular diameter \( D_p \) are considered isolated if any neighbour with diameters \( D_i \) (with \( D_i/4 \leq D_i \leq 4D_p \)) has an apparent angular separation \( R_{ip} \) from the primary galaxy, greater than \( 20D_i \).

This criterion statistically implies that all possible effects of a past interaction on the morphological or dynamical properties of a CIG galaxy, or those concerning the enhancement of star formation processes, have likely been erased at the present time. Because this represents a lower limit on the time since the last interaction between a CIG galaxy and a potential neighbour, the CIG galaxies have apparently been isolated for much (if not all) of their existence. For instance, for a CIG galaxy with \( D_p = 3' \), no neighbour with \( D_i = 12' \) may lie within 240' and no neighbour with \( D_i = 0'75 \) may lie within 15'. If one assumes an average \( D_p = 25 \text{ kpc} \) for a CIG galaxy and a typical "field" velocity \( V = 150 \text{ km s}^{-1} \) then an approximately equal mass perturber would require \( 3\times10^9 \text{ years} \) to traverse a distance of \( 20D_i \) (Stocke 1978).

This is a conservative criterion in the sense that, since no redshift data is used for the isolation definition, a truly isolated galaxy may be excluded from the CIG due to a projected background/foreground neighbour: galaxies isolated in space do not necessarily appear isolated in the sky. As a result of these projection effects the CIG is not fully complete. Nevertheless, the sample is still reasonably complete, according to the Schmidt (1968) luminosity volume test which gives \( <V/V_n> = 0.42 \) at a Zwicky magnitude of 15.0 (Huchra & Thuan 1977, Xu & Sulentic 1991, Toledo et al. 1999, Verdes-Montenegro et al. 2005). On the other hand all galaxies that are included should be isolated. The CIG is a sample of galaxies isolated from similarly sized neighbours, but it is clear that dwarf neighbours are not excluded.

Several refinements of the CIG have been performed since its selection. Karachentseva (1980) discussed her isolation criterion and found that 24 galaxies (with known radial velocities) passed the isolation criterion and belong to pairs, groups, or clusters. Other authors (Stocke 1978, Haynes & Giovanelli 1984, Xu & Sulentic 1991) reported that some CIG galaxies are, in fact, members of interacting systems: CIGs 6, 7, 80, 197, 247, 278, 324, 347, 349, 444, 469, 559, 663, 781, 802, 809, 819, 850, 851, 853, 938, 940, 946, 1027, 1028.

Adams et al. (1980) and Karachentseva (1986\(^2\)) refined the original isolation criterion by assigning the following codes:

- Code 0: Isolated according to Karachentseva (902 galaxies);
- Code 1: Marginally isolated (85 galaxies);
- Code 2: Member of a group or cluster (64 galaxies).

A few detailed studies of CIG galaxies (recognised as very isolated) also exist, see for instance: CIG 947 (Verdes-Montenegro et al. 1995); CIG 121 (Karachentsev et al. 1996); CIG 710 (Verdes-Montenegro et al. 1997); CIGs 164, 412, 425, 557, 684, 792, 824, 870, 877 (Marcum et al. 2004); CIG 96 (Espada et al. 2005).

The CIG is complemented by catalogues of isolated pairs, triplets and compact groups (largely quartets); none of them take into account more hierarchical systems.

#### 3.2. Would the Galaxy belong to the CIG?

In order to illustrate Karachentseva’s isolation criterion we have applied it to the Milky Way for which the distances and sizes of its neighbours are relatively well known (Grebel 2006).

The Milky Way is a common spiral galaxy (its stellar mass is about \( 10^{11} \text{ M}_\odot \)), with a disk of about 30 kpc in diameter. Hence, all the galaxies which would possibly violate the Karachentseva’s criterion would have diameters between \( \sim 7.5 \) kpc for the smallest and 120 kpc for the largest. As the neighbour galaxies can lie at a distance as large as 20 times their diameter away, we would have to check for all the members within 2.4 Mpc. Among the nearby groups of galaxies, only the Sculptor group (1.8 Mpc away) lies inside this limit, the others are all further than 3 Mpc, hence not concerned (M 81: 3.1 Mpc; Centaurus: 3.5 Mpc; M 101: 7.7 Mpc; M 66 + M 96: 9.4 Mpc; NGC 1023: 9.5 Mpc; etc.). The Sculptor group has six members: NGC 253 (diameter of 14.4 kpc), the brightest galaxy of the group, would not violate the isolation criterion.

Hence, the question of the isolation of the Milky Way would only involve galaxies of the Local Group. Our galaxy’s brightest satellite systems are the Magellanic Clouds. The Large

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\(^2\) Unpublished documentation supplied with the catalogue by the Centre de Données Astronomiques, Strasbourg.
Magellanic Cloud is 49 kpc away and has a diameter of \( \approx 9.3 \) kpc: this neighbour violates Karachentseva’s criterion. The Small Magellanic Cloud has a diameter of about 5.4 kpc and would not be taken into account by Karachentseva’s criterion: we see here a limitation of the criterion which does not take into account dwarf companions, already mentioned in the previous section.

Belonging to the local Group but farther away, the Andromeda Galaxy (M 31) has an apparent angular major diameter of 190', corresponding to about 40 kpc. Its influence would affect any galaxy as far as 800 kpc from it, according to the Karachentseva’s criterion. Since the distance separating the Milky Way from the Andromeda galaxy is about 725 kpc, this latter would also violate Karachentseva’s criterion. On the other hand, the Triangulum galaxy (M 33) is about 840 kpc away and, due to its relatively small diameter (\( \approx 16.2 \) kpc), would not exert any noticeable influence on the Milky Way. This would be true if the system Milky Way-M 33 would have been seen in the best case (the line of sight perpendicular to the plane defined by the two galaxies). If the system is seen from other points of view, the apparent distance separating the two galaxies will become smaller and reach a point where the Milky Way would no longer appear isolated relative to M 33. This illustrates the above referred effect of incompleteness induced by a strong definition of isolation, depending on apparent 2D distances.

4. The AMIGA revision

Despite the various revisions by the authors cited in Sect. 2, we chose to improve Karachentseva’s sample by checking in an automated, homogeneous way the isolation of the galaxies and by listing/classifying the neighbour galaxies.

4.1. The sample

We have excluded from our revision all the CIG galaxies with radial velocities lower than 1500 km s\(^{-1}\) (100 galaxies, see Fig. 1 for the velocity distribution of all the CIG galaxies) since, as pointed out by Stocke (1978) and Haynes & Giovanelli (1984), the area searched for potential neighbours of nearby CIG galaxies is spread over a large surface on the sky, which makes the search overwhelming. Our final target sample is composed of 950 CIG galaxies.

4.2. Data analysis

We developed an original method to check the isolation of the CIG galaxies. This work was motivated by the fact that objects brighter than an apparent magnitude \( m_B \approx 17.5 \) are misclassified at a high rate in present on-line reductions of the all-sky Schmidt surveys. Fainter than \( m_B \approx 17.5 \), the mean isophotal surface brightness of stars begins to be comparable with that of many galaxies, and the number of pixels per source at this level (assuming a typical isophotal threshold of \( \mu_B \approx 23.5 \)) is too small to unambiguously differentiate stars and galaxies on the basis of shape. In the following, we describe the method used to reliably identify bright (i.e. \( m_B < 17.5 \)) galaxies around our CIG fields of interest.

4.2.1. Size of the studied fields

In order to recover the bright galaxies with high success rate, we reduced bright image classification in our CIG fields using Palomar Observatory Sky Survey (POSS-I E, central wavelength = 6510 Å) images obtained with the Digitised Sky Survey (DSS). We have assembled a software pipeline for producing star/galaxy catalogues in the area around each CIG field. The digital images have a pixel size of 25 \(\mu\)m (1″/7/pixel).

We chose to evaluate the isolation degree in a minimum physical radius of 0.5 Mpc (\( H_0 = 75 \) km s\(^{-1}\) Mpc\(^{-1}\)), centred on each CIG galaxy (see Fig. 2). Assuming a field velocity of 150 km s\(^{-1}\), it would require at least \( 3.2 \times 10^9 \) years for a neighbour to travel over this radius. Due to pipeline capacity and server limits, we could not handle fields larger than \( 55' \times 55' \). To reach the physical radius of 0.5 Mpc, the fields requiring a larger size were composed of various \( 55' \times 55' \) fields, with a small strip overlapping between two adjacent fields. We developed a tool to keep only one source when an object was detected more than once in adjacent fields. Below, we show the number of CIG galaxies in each field size employed:

- 767 galaxies with \( 55' \times 55' \);
- 134 galaxies with multi-fields \( 110' \times 110' \);
- 49 galaxies with multi-fields \( 165' \times 165' \).

The \( 55' \times 55' \) fields concerned galaxies with an observed recession velocity greater than 4687 km s\(^{-1}\) (including the 62 galaxies with no velocity data, see Table 1); the \( 110' \times 110' \) multi-fields correspond to galaxies between 2343 and 4687 km s\(^{-1}\); the \( 165' \times 165' \) multi-fields to recession velocities between 1500 and 2343 km s\(^{-1}\).

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4.2.2. Detection of the sources

We used SExtractor (Bertin & Arnouts 1996) to detect the sources in the images, with a threshold 3 times higher than the root mean square of the background estimation. Before the source extraction we applied a Gaussian convolution with a full width at half maximum of 2 pixels and a size of 5 square pixels. Then, all the objects larger than 4 pixels were detected, which corresponds to a diameter smaller than 2 kpc at the typical distance of the CIG galaxies (corresponding to a velocity of about 6500 km s$^{-1}$, see Fig. 1).

4.2.3. Star/galaxy separation

The images were reduced using AIMTOOL in LMORPHO (Odewahn 1995, Odewahn et al. 1996, 2002), and a Graphical User Interface (GUI) driven star/galaxy separation procedure was used to classify detected sources as: STAR, GALAXY or UNKNOWN (for the faint, low resolution sources). Star/galaxy separation was performed in the log(area) vs. magnitude (SExtractor MAG_ISO), which was found to robustly isolate the stellar locus brighter than $M_B \approx 17.5$ in a random sample of Schmidt plates. A typical star/galaxy separation parameter plane from a POSS-I E image (CIG 714) is shown in Fig. 3. The galaxies have a lower surface brightness than the stars and in the Log(area) vs. magnitude plane, the two classes of objects fall in different loci (Leon et al. 2000). The stellar locus in Log(area) vs. magnitude plane was manually located using an interactive GUI approach because the shape and location of this locus changes significantly on different POSS-I Schmidt plates. All the points that lie above the curve defined by the blue filled circles (which is described with a cubic spline) were classified as GALAXY. The points below this curve were classified as STAR. Points lying outside the spline range (brighter or fainter in magnitude than the extent of the red points) were classified as UNKNOWN. As a final step, we archived our catalogues in the form of ASCII files.

Fig. 3. Star/galaxy separation parameter plane. The objects above the separation line (blue points) are classified as GALAXY, while the ones below are classified as STAR. The objects fainter than the extent of the separation line are not classified, their type is UNKNOWN.

4.2.4. Visual checks

For a visual check, the GUI allows the user to view the image catalogue in the form of coloured-ellipse markers over-plotted on the DSS image (see Fig. 4). The blue ellipses indicate the galaxies detected, the red ones over-plot the stars and the green circles mark the sources that were not classified. One of us (S. V.) systematically verified all the objects (GALAXY, STAR and UNKNOWN) and changed the types if needed. This task was very time consuming as the mean number of objects detected amounted to 4000 per single 55 154 field (up to 14 000 at low galactic latitude). This visual quality control check was necessary to reject cases of blended stellar images, which can occur at $m_B < 17.5$ with a non-negligible frequency, especially at increasingly lower galactic latitudes ($b < 45^\circ$).

Finally, we also used POSS-II red (IIIa-F) plates of all our galaxy objects to perform a second check of our final catalogues of neighbours (55 154 stamps, visually checked by L. V.-M.). The choice of POSS-II instead of POSS-I for this final check removed the detected plate defects in the POSS-I survey that could have passed through our first revision and provided a better spatial resolution to distinguish compact galaxies from stars. We summarise the results of this second visual inspection of the galaxy objects: 98% were confirmed as GALAXY ($\sim$ 54 000 objects), almost 2% were plate defects (1119 sources), while 0.04% were STAR (23 objects).

5. Redshifts of the catalogued neighbours

In order to evaluate the physical association of the (projected) neighbours with the CIG galaxies, we searched for available redshifts in the bibliography. As explained above, Karachentseva did not use redshifts to produce the CIG, since at that time few of such data existed. Nowadays we are able to use more than a dozen databases and surveys in order to search for the redshifts and determine whether the catalogued neighbours are physically associated with the CIG galaxies or just projected objects. We used batch routines for all the 54 000 neighbours to access each database, matching the coordinates within a tolerance of 6$''$. 

Fig. 4. Close-up view of the distribution of galaxies around CIG 714 (the bottom-right galaxy). The detected galaxies are marked with blue ellipses, the stars are marked by red ellipses. The objects too small or to faint to be assigned a type are shown by the green ellipses. The plate defects were removed from our object extraction.
5.1. Redshift compilation

We compiled all the data coming from the various databases (listed in the first column of Table 2). We treated the different formats in order to obtain one single, homogeneous (J2000 coordinates, heliocentric velocities) final catalogue. A total of 16126 objects have a redshift listed in at least one database. The second column of Table 2 lists, for each database, the total number of available redshifts.

The typical reported error on the velocities is about \( \pm 40 \text{ km s}^{-1} \). For some galaxies, the redshifts were listed several times, in various databases. The agreement is generally very good (less than \( \pm 10 \text{ km s}^{-1} \)) between the different databases. Only one redshift per neighbour was kept for the following study. To have the most homogeneous final database, we chose to preferentially keep the data from the largest surveys. The Sloan Digital Sky Survey (SDSS) gave 12166 objects (75% of the redshift sample) and besides this it gave the smallest error parameters of the detected objects about two times smaller than the expected estimation of \( D_p \), since the typical 3-sigma for a POSS-I Schmidt background results in a brighter detection level of \( \mu_0 \approx 23.5 \text{ mags/sq. arcsec} \). In each field, we calculated the scale factor between the known \( D_p \) (from NED) and the SExtractor value of the CIG diameter. We applied this scale factor to the diameters of the neighbours in order to have an estimated value of their true \( D_p \). When the scale factor was outside 2 or from the mean factor calculated with the CIG galaxies, we decided to replace it by the mean value (equal to 2). Hence, in these fields, the SExtractor factors of the neighbours were multiplied by 2 to infer the values of the \( D_p \).

In Fig. 5, we show the distribution of the size of the neighbour galaxies with respect to the size of the associated CIG galaxy. Very few neighbours have a diameter larger than the diameter of their associated CIG galaxy. The distribution increases exponentially as the diameters of the neighbours get smaller: the peak of the distribution is reached for the neighbours having diameters of about one fourth the size of the diameter of the associated CIG galaxy. This corresponds to the nominal factor used by Karachentseva: the sizes of the neighbours taken into account by Karachentseva’s isolation criterion are not equally distributed between 0.25 and 4\( D_p \), the vast majority of the neighbours (about 88%) are at least two times smaller than their associated CIG galaxy.

Taking also into account the neighbour galaxies having a diameter less than 0.25 \( D_p \), allows us to go a step further and not only exclude major interactions but to establish a gradient in the degree of isolation with respect to small satellites. This will be the subject of a further article (Verley et al. 2007, in prep.).

6. Discussion

6.1. Karachentseva’s criterion in light of available new information

For practical reasons we could not cover fields as large as the needed ones to fully verify Karachentseva’s criterion, but we were still able to find some of the CIG galaxies that failed her criterion. According to Karachentseva, a perturbative neighbour can be 4 times bigger and 20\( D_p \) away from the CIG galaxy. This is a huge distance: 20\( D_p \) = 20 \( \times 4D_p \) = 80\( D_p \). We could only cover this area for 74 fields: among them, 58 CIG galaxies are isolated following Karachentseva’s criterion, while 16 are not isolated.
Table 3. Catalogue of the neighbours of the CIG galaxies.

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†The full table is available in electronic form at CDS or from http://www.iaa.csic.es/AMIGA.html.

Fig. 5. Distribution of the major axis of the neighbours with respect to the major axis of their associated CIG galaxy. The red dashed line represents the lower limit defined by Karachentseva to consider a neighbour as a potential perturber.

For the remaining fields, although we were not able to check the whole 80 × Dp, we have found 284 CIG galaxies violating Karachentseva’s isolation definition. Still, 666 CIG galaxies remain isolated accordingly to Karachentseva, taking into account that we cannot assert that some of these latter galaxies will not move from the “isolated” to the “not isolated” sample, if studying a larger field.

The majority of the neighbours (30 407 galaxies, 57.3%) have sizes similar (within a factor of 4) to the one of their associated CIG galaxy, but only 1.4% of companions (734) are within 20 times of their diameters away from the CIG galaxy. We find that 465 neighbours cumulate the two conditions, hence violating Karachentseva’s criterion. As several of these neighbours could be in the same field around one given CIG galaxy, a total of 284 CIG galaxies were concerned.

Two columns of Table 3 summarise these conditions: Column 9 is “1” if the neighbour is within 20 D, and equal to “0” if it is farther away; Column 10 is “1” if the neighbour has a diameter similar to the one of the associated CIG galaxy (factor 4 in size) and equal to “0” otherwise. If at least one of the two conditions is false, multiplying the last two columns, we find 0 which means that the CIG galaxy is still isolated according to Karachentseva’s criterion; if the two conditions are true, the multiplication gives 1: the CIG galaxy it is not isolated according to Karachentseva’s criterion.

6.2. Redshifts

The distribution of the velocities available for the neighbour galaxies is presented in Fig. 6. The mean recession velocity for the neighbour galaxies is about 27 000 km s⁻¹. Comparing this value with the distribution of the CIG galaxies’ recession velocities (Fig. 1) showing a mean at about 6624 km s⁻¹, it appears that the neighbour galaxies represent a deeper sample of galaxies than the CIG. Hence, most of the neighbour galaxies are background galaxies and although some of the CIG galaxies violate Karachentseva’s strict criterion, most of them still represent a valuable population of isolated galaxies.
6.3. Pair candidates

As almost one third of the CIG galaxies failed Karachentseva’s original criterion, we chose to lead a systematic study to identify CIG galaxies possibly belonging to a pair system. The pair candidates are defined as a CIG galaxy with at least one neighbour (factor 2 in size with respect to $D_p$) within $5 \times D_p$. Table 4 lists the 10 pair candidates found accordingly. The entries are:

- Column 1: CIG number and neighbour number;
- Column 2: Right Ascension (in °, Epoch J2000);
- Column 3: Declination (in °, Epoch J2000);
- Column 4: Projected distance (in ″) from the neighbour to its associated CIG galaxy;
- Column 5: Diameter of the galaxy (in ″);
- Column 6: Recession velocity (when available, in km s$^{-1}$) of the galaxy.

CIG 19 has 2 neighbours nearby, one without known velocity and one with a recession velocity very similar to the one of the CIG galaxy: this constitutes a physical pair. Among the 4 other pair candidates having velocity information, 3 CIG galaxies are physically associated with their neighbours (CIGs 74, 488, 533) which is clearly not the case for CIG 683 (velocity difference of $\sim 10\,000$ km s$^{-1}$).

Unfortunately, no velocities are available for the neighbours of the 5 remaining pair candidates (CIGs 36, 178, 233, 315, 934). But, as four out of five pair candidates appeared to be real pairs when the velocity is known, we can expect that, again, about 80% of the 5 pair candidates would be physically bounded.

6.4. Difference in velocity for a factor 4 in size

In order to determine some of the characteristics of the neighbour population considered by the Karachentseva’s criterion, we have been able to estimate to what velocity difference the factor 4 in size defining the original isolation criterion corresponds. First, we can see (Fig. 7) that the similar size (factor 4 in size with respect to the associated CIG galaxy) population dominates up to a velocity difference of $20\,000$ km s$^{-1}$ (the mean value is about $17\,700$ km s$^{-1}$). This high value for the velocity difference between the neighbours and the CIG galaxies makes the CIG a very restrictive sample compared to others (mainly cuts at 500 or 1000 km s$^{-1}$). For velocity differences larger than $20\,000$ km s$^{-1}$, the other sample (neighbours having a size smaller than $0.25D_p$ or greater than $4D_p$) dominates: the mean value is about $25\,700$ km s$^{-1}$.

Second, the distributions of the two samples appear mixed due to the intrinsic recession velocity of each galaxy (the standard deviation is quite large: about $14\,000$ km s$^{-1}$ for each sample), which is not a bijective function of the size. This indicates that we need to take into account also the small neighbours (size minor than $4D_p$) that could have a velocity similar to the one of their associated CIG galaxy and exert a noticeable influence. A further analysis is needed to take into account this effect: this is discussed in a following paper (Verley et al. 2007, in prep.).
magnitude at 3 is a rather good approximation because it loses only 10% of the neighbours selected by Karachentseva on the basis of the linear size of 4. But the contamination also shows that the hypothesis of flat surface brightness profile of galaxies is not always true: the cut in magnitude includes a large number of galaxies not considered by Karachentseva. Hence, the two definitions to seek for the neighbours are not fully equivalent.

7. Summary and conclusions

We have performed a systematic study to list all the projected neighbours, down to a magnitude $m \sim 17.5$, lying within 0.5 Mpc around the CIG galaxies. Our conclusions are the following:

1. Using automated classification, some of the galaxies in the CIG appear not to be isolated according to Karachentseva’s original criterion. Nevertheless, this remains a valid sample as a starting point to obtain a refined sample of isolated galaxies. We give a first catalogue distinguishing the isolated galaxies from those failing the original criterion: a systematic and visual inspection of the objects lead to about 54 000 neighbours.

2. We looked for the available redshifts of the neighbour galaxies in 12 databases: 30% have known velocities, and the neighbour galaxies represent statistically a background population, with respect to the CIG galaxies.

3. We identified some physical pairs and pair candidates. When a neighbour galaxy is found very near in projection from the central CIG galaxy, its probability of being a physical companion is high.

4. The factor 4 in size defined in the original criterion takes into account the major size differences up to a velocity difference of 20 000 km s$^{-1}$, which makes the CIG original criterion much more restrictive than commonly used criteria which use velocity differences of about 1000 km s$^{-1}$.

5. Criteria based on magnitude differences to select the neighbours are not fully consistent with Karachentseva’s criterion based on the linear sizes. The discrepancy arises from the fact that the surface brightness profile of galaxies is not flat, but nevertheless they are similar criteria to a first approximation.

6. A catalogue of the ∼ 54 000 neighbour galaxies is available electronically at the CDS with positions, magnitudes, areas as well as redshifts when available.

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Fig. 8. Comparison of the magnitude difference distributions for the neighbour galaxies considered by Karachentseva’s criterion (factor 4 in size with respect to their associated CIG galaxy, grey histogram) and for the remaining neighbours (outside the factor 4 in size, unfilled histogram).
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