Visual Survey of 18 020 Objects from the 2MFGC Catalog

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We conducted a continuous survey of infrared and visual images of 18 020 2MFGC galaxies which were selected on an automatic basis from 1.64 mln extended objects of the 2MASS XSC catalog based on the ratio of the infrared axes \( a/b \geq 3 \). This work aims to exclude “false” objects from the list of flat galaxies. Having observed more than 80 thousand images in different filters, we were able to detect 1512 such objects (8.4% of the total number). We found 23 galaxies duplicated in 2MASS, which have two 2MFGC numbers correspondingly, and three flat galaxies which are not included in other catalogs and are located close to three “false” galaxies. Galaxies with magnitudes fainter than \( K_s = 13 \) compose the main part of the excluded objects. They show small angular sizes, low surface brightnesses and concentration ratios. The results of the work in the form of the 2MFGC table with notes are given in the astronomical databases VizieR,¹ NED, HyperLeda.

1. INTRODUCTION

Nowadays, the researchers involved in the studies of different cosmological parameters of the Universe, large-scale peculiarities of the galaxy distribution, their collective motions, and also structural features of disk galaxies direct their attention to the spiral edge-on galaxies with thin disks. In 1993 the catalog of 4455 flat spiral edge-on galaxies, FGC [1], was published; it was compiled based on a continuous review of blue edge-on galaxies, FGC [1], was published; it was compiled based on a continuous review of red and blue images from the POSS-I and ESO/SERC surveys. It consists of two parts: FGC (Flat Galaxy Catalogue) itself, covering the region \( \delta > -20^\circ \), and its southern extension FGCE (Flat Galaxy Catalogue Extension), \( \delta < -20^\circ \). The catalog includes objects with the maximum angular diameter \( a_{\text{lim}} = 0^\circ 6 \) and the axial ratio \( a/b \geq 7 \), where \( a \) and \( b \) are the major and minor axes respectively. Eventually, in the Digital Sky Survey (DSS), the coordinates of all the objects were measured again with an accuracy of up to 3″; the diameters determined with the films from the ESO/SERC survey were adjusted to the POSS-I [2] diameter system; the total visible \( B_t \) magnitudes were derived, which correspond to the \( B_t \) values from RC3 [3] with an accuracy of up to 0″25. As a result, the improved and extended edition of the RFGC catalog (Revised Flat Galaxy Catalogue) [4] was released; it comprised 4236 flat galaxies with the extreme axial ratio \( (a/b)_{\text{lim}} = 7 \). The galaxies with reduced diameters \( a < 0^\circ 6 \) were excluded from the RFGC list. At present, the RFGC catalog is frequently used for studying the characteristics of the star formation rate, large-scale flows of galaxies, structural features of disk systems, etc. [5–10].

Current deep sky surveys provide new possibilities for the detection of objects of such type. Since 2006, using the observational data from a deep sky survey in the visible \( (u, g, r, i, z) \) range—Sloan Digital Sky Survey (SDSS) [11]—a catalog of edge-on disk galaxies is being compiled on an automatic basis [12–15]. By now, the SDSS survey covers a quarter of the sky, and 5747 edge-on galaxies have been found in this area.

As is well known, global cosmological investigations require a homogeneous sample of galaxies all over the sky with sufficient spatial depth and accuracy of both the coordinates and the measured values. The best all-sky surveys in terms of the listed parameters are those conducted in the same manner and with similar instruments and devices. By the end of the year 2000, such surveys were the Two Micron All-Sky Survey (2MASS) [16] and the Extended Sources Catalog (XSC) [17] compiled on its basis. One of the most significant advantages of this catalog, and also the main reason why the 2MASS survey was conceived, is the low absorption of our Galaxy in the infrared (IR) range compared to the visible one. Thus, in the IR-range the Galaxy becomes more transparent for the search for remote ob-
objects in the direction of its stellar disk [4], which prompted us to compile a catalog of flat galaxies selected from 2MASS.

The objects for the catalog of disk-like galaxies—the 2MASS-selected Flat Galaxy Catalog (2MFGC) [18], comprising 18 020 objects all over the sky—were automatically selected from 1.64 mln extended objects of 2MASS XSC. Among the objects with \( K_s < 14^m \) and angular diameters larger than \( 7'' \), we selected the objects with axial ratios \( b/a \leq 0.34 \) or \( a/b \geq 3 \), which corresponds to the visible axial ratio \( a/b \geq 6 \). The axial ratios both on the combined \( J + H + K_s \) image (\( sba \)) and in each filter were taken into consideration. Our choice of this criterium was driven by the comparison of the infrared and optical characteristics of the RFGC galaxies [7].

The main goal of compiling the flattened galaxy catalog is to obtain the deepest, morphologically homogeneous sample of spiral field galaxies across the sky. Unlike other available optical catalogs, e.g., the RFGC [4], the 2MFGC catalog seems to be more relevant for the studies of cosmic streams on a scale of \( z \approx 0.1 \). For example, it was shown in [18] that the dipole moment of the distribution of bright \((K < 11^m)\) 2MFGC objects \((l = 227^\circ, b = 41^\circ)\) is within the statistical error \((\pm 15^\circ)\) in the direction of the IRAS dipole and the optical RFGC dipole.

It is known that the high brightness of the night sky in the near-IR region and the short exposures (about 8 s/object) of 2MASS [19] make the selection of extended sources difficult. As a result, the periphery of spiral galaxy disks is not usually seen in the isophotes fainter than \( K_s = 20^m/\Omega'' \). This, in turn, results in the fact that, on the one hand, bright galaxies with low surface brightness and late-type morphology can be omitted from the XSC catalog. It is shown in [7] that from 4236 edge-on RFGC galaxies, only 2996 (71%) were detected in 2MASS, and the data on them are available in the XSC catalog. About 18% of these 2996 RFGC galaxies are not included in the 2MFGC catalog, as their axial ratios \((b/a \geq 0.34)\) are beyond the selection criterium limits of the 2MFGC. On the other hand, for the same reason “false” objects may be included in the XSC: the result of overlapping when performing the photometry of a pair or a chain of galaxies or stars, a galaxy and a projected star (stars), and also galaxies with an elongated red bar or a bulge, the spiral structure of which is detectable only in the visible range. To reduce the influence of such errors, in the course of compiling the 2MFGC catalog we reviewed several thousand images of galaxies on the \( J, H, K_s \) frames from the 2MASS and DSS1 catalogs. However, in the course of time the necessity of total revision of the images of 2MFGC objects became obvious. Generally, this work aims to exclude “false” objects in order to improve the accuracy of future investigations.

2. VIEWING TECHNIQUE FOR INFRARED AND VISIBLE IMAGES OF 2MFGC OBJECTS

A continuous review of available images of 2MFGC objects was conducted with the \( J, H, K_s \) 2MASS frames and their sum in the NED\(^1\) and DSS2-red database systems; we used the DSS2-blue, DSS2-infrared and DSS1\(^2\) for refining, and it was possible to use the combined images from the Sloan Digital Sky Survey (SDSS III) DR9\(^3\) for about a quarter of the objects. Eventually, we provided the 2MFGC table with notes and placed it in the astronomical electronic databases VizieR, NED, HyperLeda.

Figures 1 and 2 show examples of several infrared and visible galactic images left in the catalog (Fig. 1) and the objects which were, for one reason or another, wrongly classified as flat galaxies (Fig. 2). The combined \( J + H + K_s \) 2MASS images are given on the left, the DSS2 or SDSS images of the same objects are shown on the right.

The 2MFGC 813 galaxy, given in the first pair of images, shows almost an ideal case (Fig. 1). The vast majority of visually selected galaxies are similar to it. The second (2MFGC 895, \( b = -5^\circ 5 \)) and third (2MFGC 1119, \( b = 0^\circ 6 \)) pairs show complicated variants of the galaxies’ location in the Zone of Avoidance, where the density of our Galaxy’s stars is high. They were qualified as satisfactory based on the formal selection principle, however, in the reference for 2MFGC 895 we noted the presence of a bright star nearby, and the red galaxy 2MFGC 1119, scarcely noticeable in the visible region in the DSS, was included in

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1 http://ned.ipac.caltech.edu
2 http://archive.eso.org/dss/dss/
3 http://skyserver.sdss3.org/dr9/en/tools/chart/navi.asp
the list without any references. The fourth pair (2MFGC 9495) is an example of a flat galaxy interacting with another galaxy. In 2MASS, both galaxies are separately detected. Other pairs of interacting galaxies, such as 2MFGC 151 (Fig. 2), were excluded from the list, because when measured photometrically in 2MASS, both non flat galaxies were combined into one object. This resulted in the elongated shape of the object, and the position angle was measured by the line connecting the two galaxies. A similar asymmetry in the infrared image of an object also appears with galaxy and (or) star chains, e.g., MFGC 673, in Fig. 2. The third pair of images in Fig. 2 (2MFGC 9497) shows an example when a galactic bar is seen in 2MASS and the spiral struc-

Figure 1. Examples of confirmed galaxies from 2MFGC. The combined $J + H + K_s$ 2MASS images (on the left) and the DSS2 or SDSS images (on the right).
ture is noticeable only in the visible range. The last pair of images is an example of the small bright part of the 2MFGC 10867 galaxy marked in 2MASS.

The first review of images of all the objects from the 2MFGC allowed us to detect more than 2000 objects which are asymmetric or have a nodular structure in the IR range while their shape in the visible range is more rounded than in the IR range, or they have a multiplet structure, and some cannot be seen at all. In the course of further comparison of the 2MASS images \((J, H, K_s)\) and the DSS1, DSS2, and SDSS images of the detected objects and

**Figure 2.** Examples of objects excluded from 2MFGC. The combined \(J + H + K_s\) 2MASS images (on the left) and DSS2 or SDSS images (on the right).
their vicinities, and also considering their sizes, distances, location, orientation, and positional angles measured in 2MASS, we selected 1512 "false" objects, which make up 8.4% of their total number in the catalog. In the references to the electronic table (see the footnote on page 2), the following abbreviations are used for the remarks why they cannot be considered flat objects:

- PofG—close pairs of galaxies;
- GG—multiple galaxies;
- G + S—a star which was not excluded from galaxy photometry;
- SS—multiple stars;
- IRbar—only a bar or a bulge of a galaxy is seen in 2MASS;
- IRcen—only the central part of a galaxy is seen in 2MASS;
- PART—only a certain part of a galaxy is seen in 2MASS;
- nEon—a galaxy is not flat;
- asymm—an asymmetric form of a galaxy of unknown nature;
- Interacting—interacting systems;
- 2obj, 3obj—multiple objects of small angular sizes;
- MIST—damaged 2MASS images.

The objects marked with the # sign in the catalog references, in our view, should be excluded from the list. Near the three "false" objects with the 2MFGC numbers 3795, 5287, and 14518, we found several new flat galaxies which have never been mentioned before in any catalogs including 2MASS XSC, on which the 2MFGC is based. Table 1 shows the number of the 2MFGC objects marked in the catalog with the mentioned abbreviations. About 80 objects were excluded from the catalog for two or more reasons, e.g., multiple systems often show tidal interaction, and some pairs are surrounded by other galaxies which can also be included in 2MASS photometry. According to our observations, the most "false" objects are a result of combined measurements of galaxy pairs, galaxies with a star (stars), pairs and chains of stars.

Moreover, in a closer look, 23 galaxies in the 2MASS catalog were found to be duplicated. Table 2 shows their 2MFGC numbers (columns 1 and 5), the corresponding coordinates (columns 2 and 6), galaxy numbers in the LEDA database (3), and the accuracy (4) of identifying (in fractions of a minute of arc) the first pair of coordinates with the coordinates of the object from LEDA. In the 2MFGC references, the second 2MFGC numbers are given corresponding to the considered galaxy. The sign # in the references means that we excluded from the list this one measurement of the two given.

One of the galaxies (2MFGC 6642 ≡ 6644) is considered being nonflat: the red bar of the galaxy is seen in the IR range, and the ring around it appears only in the visible range. The number of real objects in the 2MFGC catalog decreased by 23 and amounted to 17 997. Another 1512 objects are excluded as not meeting the selection criteria of the catalog. As a result, the 2MFGC catalog consists of 16 485 flat galaxies which can be used in further investigations.

Using the images of 2MFGC galaxies, we determined the morphological types for more than 3900 of them, which are also available in the references. The vast majority of such galaxies were not included in formerly known catalogs, i.e., they were first found in the 2MASS survey. Into that category fall the objects at low galactic latitudes, which claim our closer attention, as they were often registered in 2MASS at the detection threshold. In the DSS images they had a low contrast appearance or were not even detected against the sky background. When stars or galaxies with comparable angular sizes were projected near a flat galaxy, we marked them in the references with the signs: +S, +SS or +G, +GG. The signs : and ? in the references show our doubts. About seventy doubtful objects are left in the catalog, but if deeper images appear, some of these objects may turn out to be "false."

### Table 1. The distribution of 1512 objects excluded from the 2MFGC catalog

| Reasons              | Number of objects | Percentage of the 2MFGC |
|----------------------|-------------------|-------------------------|
| PofG, 2PofG, 2G, 2obj| 644               | 3.89                    |
| G + S                | 266               | 1.48                    |
| GG, GG + S, GGSS, 3obj, SS | 268           | 1.49                    |
| nEon, asymm          | 219               | 1.21                    |
| IRbar, IRcore        | 93                | 0.45                    |
| Interacting systems  | 12                | 0.07                    |
| PART                 | 5                 | 0.03                    |

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3. DIAGRAMS OF THE DISTRIBUTION OF “FALSE” GALAXIES FROM THE 2MFGC LIST

To analyze the properties of 1512 excluded galaxies, we plotted the diagrams of their distribution compared to the total number \((N = 17998)\) in the 2MFGC.\(^4\) In all histograms (Figs. 3–5), we marked the percentage of the “false” galaxies compared to the total number in a bin. The \(K_s\) distribution maximum of these objects is shifted only by 0\(^{m}\)5 to the region of faint objects (Fig. 3); however, in the same direction (greater than 13\(^{m}\)), their fraction considerably increases in comparison with all the 2MFGC objects, which can be seen from the percentage of “false” galaxies.

The figures show that the percentage of “false” objects with small \((r < 10^{\prime \prime})\) angular sizes (Fig. 4) and a low concentration index \(I_{C_j} < 2\) (Fig. 5) turned out to be much higher, which is not surprising for non deep surveys, to which the 2MASS belongs.

In the two-dimensional distributions of the \(K_s\) magnitude as a function of the axial ratio \(b/a\) (Fig. 6) averaged over the individual \(J, H, K_s\) values and the change of this \(b/a\) ratio with the change of Kron elliptical radius \(r\) measured by the twentieth isophote in the \(K_s\) filter (Fig. 7), it can be noticed that the excluded galaxies considerably increased the scatter in the diagrams. We focused on six galaxies \((7289, 9627, 9663, 10074, 10410, 11471)\) that stay away from the main concentrated cloud on the lower panel in Fig. 7, for which the actual flatness value is underestimated in 2MASS XSC, as judged by the images in 2MASS.

Based on the detailed analysis of the results shown in the diagrams, we conclude that the objects excluded do not have much influence on the general distribution of galaxies in the catalog; although, the scattering of the values decreases, mainly in the region of the objects with small angular sizes and low surface brightnesses, where the 2MASS detection threshold has its impact.

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\(^4\) Both measurements of the duplicated galaxy with the numbers 2MFGC 5793 and 2MFGC 5794 are included in this list.
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Figure 3. The distribution of galaxies by $K_s$. The histogram shows the percentage of “false” galaxies (crosshatched) compared to the total number (hatched) in each bin, the increment size is $0".5$. The total number of 2MFGC galaxies ($N$) and the number of the “false” ones ($n$) are given at the top.

Figure 4. The distribution of galaxies by angular diameters. The percentage of “false” galaxies is also shown here, the hatching is similar to Fig. 3. The total number of 2MFGC galaxies ($N$) and the number of the “false” objects ($n$) are given at the top.
Figure 5. The distribution of galaxies by the concentration index. The percentage of “false” galaxies is shown here, the hatching is similar to Figs. 3 and 4. The total number of 2MFGC galaxies ($N$) and the number of “false” objects ($n$) are given on the right.

Figure 6. The dependence of the $K_s$ magnitude on the axial ratio. The dots denote all the galaxies, the crosses—the excluded objects. The total number of 2MFGC galaxies ($N$) and the number of “false” objects ($n$) are given at the top.
Figure 7. The dependence of the axial ratio on the radius $r$ of galaxies. The upper figure shows all the 2MFGC galaxies with $r < 25''$, and the lower one—with $r \geq 25''$. The dots denote all the galaxies, the crosses—the excluded objects. The number of objects in the intervals is given on top.