Research Article

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New atlas of open star clusters

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Abstract: Due to numerous new discoveries of open star clusters in the last two decades, astronomers need an easy-to-use resource to get visual information on the relative position of clusters in the sky. Therefore we propose a new atlas of open star clusters. It is based on a table compiled from the largest modern cluster catalogues. The atlas shows the positions and sizes of 3291 clusters and associations, and consists of two parts. The first contains 108 maps of 12 by 12 degrees with an overlapping of 2 degrees in three strips along the Galactic equator. The second one is an online web application, which shows a square field of an arbitrary size, either in equatorial coordinates or in galactic coordinates by request. The atlas is proposed for the sampling of clusters and cluster stars for further investigation. Another use is the identification of clusters among overdensities in stellar density maps or among stellar groups in images of the sky.

Keywords: open clusters and associations: general

1 Introduction

Open star clusters (OCls) are very important objects for astrophysics. It is well known that theories of stellar evolution are verified by star cluster colour-magnitude diagrams. OCls show us the history of star formation in the Galactic disk, with young clusters being tracers of the Galactic spiral structure. Star clusters serve as laboratories for further stellar dynamics studies. The scientific interest in star clusters and for OCls in particular is growing.

A distinguishing feature of the last two decades is the rapid growth of the number of known open clusters, generally due to IR sky surveys, for example, Two Micron All Sky Survey (2MASS, Skrutskie et al. 2006), United Kingdom Infrared Digital Sky Survey (UKIDSS, Lucas et al. 2008), Visual and Infrared Survey Telescope for Astronomy Variables in the Via Lactea survey (VISTA-VVV, Minniti et al. 2010), and the Wide Field Infrared Survey Explorer (WISE, Wright et al. 2010). A large reference list with the discoveries of new clusters can be found in Carraro et al. (2016). As a result, the number of known OCls and candidates has increased significantly. The largest modern catalogue of star clusters (Kharchenko et al. 2016) contains 3208 objects, the catalogue of optically visible clusters and candidates (Dias et al. 2014) contains 2167 objects, and the catalogue of the Sternberg Astronomical Institute contains 168 new open clusters (Glushkova et al. 2012).

However these catalogues, accessible as tables, cannot provide all the practical needs for astronomers, because catalogues do not supply their users with a visual information about positions and sizes of star clusters. These catalogues are difficult to use without a visualisation, for example, when someone wants to compile a sample of clusters for investigation with clusters without close neighbour objects, or when someone selects stars from the cluster for investigation and tries to avoid contamination with stars from another cluster. In addition, one can face problems while attempting to identify overdensities on a map of stellar density or on an image of the sky.

Such a situation is illustrated in Figure 1. The upper panel of this figure shows the map of surface stellar density in a square field of about 2.7 degrees centred on the coordinates of star cluster NGC 7788. The map was plotted with the use of a kernel estimator (Seleznev 2016b) and the data from 2MASS (Skrutskie et al. 2006) for stars with J<16 magnitudes and with a kernel halfwidth of 5 arcminutes. It is clear that NGC 7788 is in the centre of this map, but what are other overdensities on this map? Of course, one can measure the coordinates of overdensities on the map and look for the known star clusters in the set of catalogues. However, it would be much more useful if we could

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get a graphical presentation of combined table with the cluster coordinates and sizes for the same field. The lower panel of Figure 1 shows the same map with overlapped positions and relative sizes of star clusters from the catalogue of Dias et al. (2014). Clusters marked by red have data on their sizes from the star counts of Danilov and Seleznev (1994). It is obvious that if the goal of someone is the study of the stellar content of NGC 7788, it is necessary to take into account the overlapping of projections of NGC 7788 and NGC 7790 on the celestial sphere.

Unfortunately, the existing sites and packages, which visualize the celestial sphere or its parts do not provide the solution to these problems. For example, the WEBDA online database\(^1\) shows the image of the cluster field, but does not indicate the presence of close neighbour clusters and does not allow changes to the image size. A very useful Aladin package\(^2\) has a greater functionality. But even if someone could open the catalogue of Kharchenko et al. (2016) in this package, they could not view the sizes of clusters in the sky image.

In addition, there is another problem. The sizes of open clusters are often underestimated in the existing literature, which was shown in Seleznev (2016a). Even if you could open some open cluster catalogues with the Aladin package with indication of cluster sizes, these sizes would be much smaller than the actual ones, as a rule.

The outlined problems can be solved by the new atlas of open star clusters and associations, similar to the old atlas of Alter and Ruprecht (1963), but with the data on newly discovered open clusters, their positions and actual sizes, and with modern technical realization. The atlas of Alter and Ruprecht (1963) contained only about 860 objects, now we have 4 times more clusters.

In this work we propose two realizations of the atlas of OCLs. The first realization updates the atlas of Alter and Ruprecht (1963). It is a set of maps, with every map covering a field of 12 by 12 degrees with an overlapping of 2 degrees between adjacent maps. These maps are arranged in three strips along the Galactic equator from \(-16\) to \(16\) degrees in Galactic latitude (the total number of maps is 108). The second realization is an online atlas. It shows a square field of an arbitrary size either in equatorial coordinates or in galactic coordinates.

The paper is organised as follows. In Sect. 2 we describe the procedure of combining data from the three catalogues mentioned above. Sect. 3 is devoted to the first realization of the atlas (the maps are attached to this paper as a separate pdf file). Sect. 4 describes details of the online version of the atlas and contains brief instructions for the user. Sect. 5 summarises our results and provides some discussion and future prospects for development.

### 2 The combined table for the atlas

The atlas is based on a combined table, which contains cluster names, equatorial and galactic coordinates of cluster centres, and the cluster radii in arcminutes. To compile our atlas we used the following catalogues:

1. Kharchenko et al. (2013),
2. Schmeja et al. (2014),
3. Scholz et al. (2015),
4. Dias et al. (2014),
5. The catalogue of the Sternberg Astronomical Institute, \(^3\) Glushkova et al. (2012)

All these catalogues were taken as tables and combined into one table. All coordinates were transformed into degrees and the decimal fraction of degrees. Then this combined table of \(5587\) rows was sorted in accordance to Right Ascension. The angular radii of clusters were then transformed into arcminutes. In catalogues 1-3 we used the \(r_2\) parameter as the angular radius.

At the next step, the rows with duplicated names were deleted. Catalogues 1-3 present the largest number of clusters with the largest number of uniform parameters. Then, we adhered to left rows from these catalogues in the combined table. After the removal of duplicated rows, the table had \(3476\) rows. After that, different cluster names were checked for cross matches with the help of the WEBDA database. This way we found \(26\) clusters, presented in the table with different cluster names. In the following, we compared objects in the table with a list of unconfirmed candidates by Kharchenko et al. (2013). This list was obtained through the difference between the complete list of MWSC objects (with \(3784\) rows) and the list of confirmed clusters (with \(3006\) rows) in Kharchenko et al. (2013). This way we removed \(159\) rows of the combined table, which corresponded to unconfirmed candidates. Finally, the combined table for the atlas consists of \(3291\) rows.

It is necessary to stress that cross-designation tables in the WEBDA database are very incomplete. There are many cases when one can see objects of different names in exactly the same position in our atlas. It would be

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1. http://obswww.unige.ch/webda
2. http://aladin.u-strasbg.fr/
3. http://http://ocl.sai.msu.ru/
Figure 1. (Upper panel) The map of surface stellar density in the field centred on coordinates of star cluster NGC 7788. The map was plotted with the use of a kernel estimator (Seleznev 2016b) and using the data from 2MASS (Skrutskie et al. 2006) for stars with J<16 magnitudes and with a kernel halfwidth of 5 arcminutes. (Lower panel) The same map with overlapped positions and relative sizes of star clusters from the catalogue of Dias et al. (2014). Clusters marked by red have data on their sizes from the star counts of Danilov and Seleznev (1994).
very important to have complete information about cross-
identification of different cluster designations, because in
some cases different catalogues list different coordinate
values for the same cluster. For example, the cluster NGC
6664 has the declination coordinate of −8.21 degrees in the
catalogue of Kharchenko et al. (2013) and −7.813 degrees in
the catalogue of Dias et al. (2014). Then, it is quite possi-
bly that one cluster would be shown at different positions
with different names in the atlas.

The combined table was supplemented by data on
cluster radii from Danilov and Seleznev (1994) and from
Seleznev (2016a). It has been done because cluster radii in
the catalogues listed above are underestimated (Seleznev
2016a).

3 Collection of maps

The atlas of Alter and Ruprecht (1963) contained 36 maps
along the Galactic equator with every map covering 12 de-
grees in the galactic longitude and 40 degrees in the galac-
tic latitude (from −20 to +20 degrees). We have decided to
present smaller maps (12 by 12 degrees) but in three strips
along the galactic equator with overlapping of 2 degrees
between adjacent maps. Then, our atlas consists of 108
maps; 36 maps in the strip between −16 and −4 degrees of
the galactic latitude, 36 maps in the strip between −6 and
+6 degrees of the galactic latitude, and 36 maps in the strip
between +4 and +16 degrees of the galactic latitude. These
maps show the positions of 2852 clusters (86.7 percent of
the total number in the combined table). 439 clusters have
larger galactic latitudes.

Maps have been plotted with the use of the Matplotlib
package in the Python language using the vector .svg for-
mat. Every map contains a header, which indicates the
galactic longitude interval and the galactic latitude inter-
val. Clusters are shown by open circles, the radius of the
circle corresponds to the cluster radius in the scale of the
map. The name of the cluster is in the nearest vicinity of
the circle. In some cases we used arrows in order to make
the identification easier. Due to the very close positions of
clusters many names overlapped each other and with the
circles. Then when it was necessary to edit the maps, it was
done manually. The example of the map is shown in Fig-
ure 2 for the galactic longitude of −1 < l < 11 degrees and
the galactic latitude of −6 < b < 6 degrees (page 2 of the
Atlas).

All maps are stored in the maps.pdf file, attached to
this paper. Table 1 shows the list of atlas pages and the
galactic longitude and galactic latitude intervals for every
page, which makes navigation easier.

This type of atlas is useful for fast surveying of clus-
ters in relatively large fields. It can be efficient for sampling
clusters without close neighbours for studying the cluster
structure.

4 Web application

In order to identify the known clusters on the density maps
or images of the sky, as in Figure 1, one needs to get a map
just for the same field, which is covered by their density
map or sky image. In order to make such an opportunity
possible, we have designed an online application for the
atlas. This application plots the map of the square field
with an arbitrary size either in equatorial or in galactic co-
ordinates by user request. The user can indicate the cluster
name as the field centre, or an arbitrary point in some co-
ordinate system (the equatorial or galactic one).

The combined table with the cluster data was trans-
formed into a database with the use of MySQL, a free
database service. It makes data operation easier. Python
language supports the use of this database. MySQL pack-
age is suitable for the creation of this online resource due
to its good safety, the stable operation and its high opera-
tion speed. Transformation of coordinates is executed us-
ing the Astropy package within Python, and the plotting
of the map is performed using Matplotlib package within
Python.

The online resource is based on the Django frame-
work. The Django development environment has been
chosen because it is a free framework, uses Python as a
programming language, has detailed documentation with
lots of examples, it can use MySQL as data storage, there
are many ready-to-use templates, and it is fast and effec-
tive.

The order of the programme operation is the follow-
ing.

1. The user indicates the centre of the field (by indicat-
ing the cluster name or the centre coordinates in the
equatorial or galactic coordinate system).
2. The user indicates the size of the field in arcminutes,
and the coordinate system they prefer.

4 www.mysql.com
5 www.djangoproject.com
Table 1. The list of atlas pages and its correspondence to the galactic longitude and the galactic latitude intervals.

| Longitude interval | Latitude interval | Atlas page |
|--------------------|------------------|------------|
| degrees            | degrees          | page       |
| 359...11           | +4°...+16        | 1          |
| 359...11           | -6°...+6         | 2          |
| 359...11           | -16°...-4        | 3          |
| 39°...21           | +4°...+16        | 4          |
| 39°...21           | -6°...+6         | 5          |
| 39°...21           | -16°...-4        | 6          |
| 19°...31           | +4°...+16        | 7          |
| 19°...31           | -6°...+6         | 8          |
| 19°...31           | -16°...-4        | 9          |
| 29°...41           | +4°...+16        | 10         |
| 29°...41           | -6°...+6         | 11         |
| 29°...41           | -16°...-4        | 12         |
| 39°...51           | +4°...+16        | 13         |
| 39°...51           | -6°...+6         | 14         |
| 39°...51           | -16°...-4        | 15         |
| 49°...61           | +4°...+16        | 16         |
| 49°...61           | -6°...+6         | 17         |
| 49°...61           | -16°...-4        | 18         |
| 59°...71           | +4°...+16        | 19         |
| 59°...71           | -6°...+6         | 20         |
| 59°...71           | -16°...-4        | 21         |
| 69°...81           | +4°...+16        | 22         |
| 69°...81           | -6°...+6         | 23         |
| 69°...81           | -16°...-4        | 24         |
| 79°...91           | +4°...+16        | 25         |
| 79°...91           | -6°...+6         | 26         |
| 79°...91           | -16°...-4        | 27         |
| 89°...101          | +4°...+16        | 28         |
| 89°...101          | -6°...+6         | 29         |
| 89°...101          | -16°...-4        | 30         |
| 99°...111          | +4°...+16        | 31         |
| 99°...111          | -6°...+6         | 32         |
| 99°...111          | -16°...-4        | 33         |
| 109°...121         | +4°...+16        | 34         |
| 109°...121         | -6°...+6         | 35         |
| 109°...121         | -16°...-4        | 36         |

3. If the user indicates the cluster name, then the cluster coordinates in the coordinate system indicated by the user are taken as the field centre coordinates.
4. If the user indicates the field centre coordinates in the galactic coordinate system, and wants to get a map in the equatorial coordinate system, the programme transforms coordinates from the galactic to the equatorial system.
5. If the user indicates the field centre coordinates in the equatorial coordinate system, and wants to get a map in the galactic coordinate system, the programme transforms coordinates from the equatorial to the galactic system.
6. Clusters, that fall into the field in accordance with the field size and coordinates of the field centre, are selected from the database and are plotted on the map.
7. The map in the coordinate system indicated by the user is plotted. Clusters are plotted by open circles, with radii taken from the database and plotted in accordance with the map scale. The short cluster name is displayed near the circle.

Cluster names in the combined table and in the database have been shortened in order to optimize the output on the map (to diminish the overlapping of names). Shortened names are listed in Table 2. The user of the
online atlas should indicate cluster names in accordance with this table. Some shortenings are commonly used, some of them have been adopted by authors of this paper. Other cluster names are the same as in the catalogue of Kharchenko et al. (2013). The user of the online atlas should realize that every cluster name contains the underlined symbol between the proper name and the number (for example, NGC_7789; also see Table 2).

This application will work at the following address http://astro.ins.urfu.ru/atlas.

5 Summary and discussion

This paper presents a new version of the atlas of open star clusters. The necessity for a modern atlas has risen due to a sufficient increase in the number of known clusters (by a factor of several) and a lack of possibility to get visual information on the actual positions and sizes of open star clusters with the existing tools used for visualizing the celestial sphere. The new atlas consists of two implementations. The first one is the collection of maps, the second

Figure 2. An example of the map for the galactic longitude of $-1 < l < 11$ degrees and the galactic latitude of $-6 < b < 6$ degrees (page 2 of the Atlas). The title in the upper part of the figure designates an interval in galactic longitude ($l$) and galactic latitude ($b$).
Table 2. The list of shortenings of cluster names

| Name               | Short. | Name             | Short. | Name    | Short. |
|-------------------|--------|------------------|--------|---------|--------|
| Alessi_1          | Al_1   | Juchert-Saloran_1| J-S_1  | Ruprecht_148 | Ru_148 |
| Barkhatova_1      | Bar_1  | Kharchenko_1     | Kh_1   | Saurer_1 | Sa_1   |
| Basel_10          | Ba_10  | Kronberger_18    | Kr_18  | Schuster_1 | Sch_1  |
| Berkeley_58       | Be_58  | Loden_28         | Lo_28  | Shorlin_2 | Sh_2   |
| Bochum_1          | Bo_1   | Majaess_1        | Maj_1  | Stock_18 | St_18  |
| Carraro_1         | Ca_1   | Markarian_50     | Mar_50 | Terzan_3 | Tz_3   |
| Collinder_463     | Cr_463 | Mayer_1          | May_1  | Terzan-Ju_20 | Tz-Ju_20 |
| Czernik_1         | Cz_1   | Melotte_20       | Mel_20 | Teutsch_55 | Te_55  |
| Dolidze_12        | Do_12  | Negueruela_1     | Ne_1   | Tombaugh_4 | Tomb_4 |
| Dutra-Bica_83     | DB_83  | Palomar_1        | Pal_2  | Trumpler_2 | Tr_2   |
| Feinstein_1       | Fe_1   | Pfeiderer_3      | Pi_3   | Turner_12 | Tu_12  |
| Frolov_1          | Fr_1   | Pismis_27        | Pi_27  | vdBergh-Hagen_19 | vdBH_19 |
| Graham_1          | Gr_1   | Pismis-Moreno_1  | Pi-Moreno_1 | Westerlund_2 | We_2   |
| Harvard_9         | Ha_9   |                  |        |         |        |

one is the online application. Each implementation serves different tasks.

The collection of maps is useful for fast surveying of clusters in relatively large fields. It can be efficient, for example, for sampling clusters without close neighbours to study the cluster structure. The online application could be very useful for identification of the known clusters on the density maps or images of the sky. The atlas contains available information on cluster sizes, determined by detailed star counts (Danilov and Seleznev 1994, Seleznev 2016a). These cluster sizes are larger, as a rule, than cluster sizes determined with the automated reviews (Seleznev 2016a) and reflect the fact of the existence of vast cluster coronae (Danilov et al. 2014).

Further work needs to be done to continue the development of the atlas. Publications with newly found clusters are going on, for example, Loktin and Popova (2017) found 48 new possible candidates. Some objects are shown not to be real clusters after detailed investigations (for example, Pismis 14 in Carraro et al. (2017), and ES0131SC09, NGC 5284 and vdBergh-Hagen 164 in Carraro and Seleznev (2012)). It is necessary to find all double mentionings of the same cluster with different names. Maybe, it is worthy to indicate unconfirmed candidates with a different colour (it is possible, that some of them will restore their status in the future). The future Gaia catalogue will cause the number of known clusters to increase, and the revision of the status of many objects.

The authors realize that the terms 'cluster', 'cluster candidate' and 'unconfirmed candidate' are rather relative to some extent. The majority of objects in our atlas are from the catalogue of N.V. Kharchenko and her co-authors (Kharchenko et al. 2016). They refer to all these objects as 'clusters', and it is confirmed by their analysis, which includes an analysis of proper motion data (see Kharchenko et al. 2016 and references therein). We are following their terminology. However, the data on many of these objects is very few, and the precision of proper motion data is often not high. Consequently, it is possible that the status of many objects in this catalogue could be revised in the future, especially taking into account future high-precision proper motions of Gaia and possible detailed investigations of open clusters by photometry and spectroscopy. The authors plan to follow up on this new available information on the reality of clusters and to take into account this information in future versions of the atlas.

The authors also will continue this work by adding the new available information on open cluster sizes. We hope that the atlas of open star clusters presented in this paper will be a helpful tool for astronomers.

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