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A Multi-band Catalog of 10978 Star Clusters, Associations, and Candidates in the Milky Way

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Abstract

We present a catalog of Galactic star clusters, associations and candidates with 10978 entries. This multi-band catalog was constructed over 20 years, starting with visual inspections on the Digital Sky Survey and incremented with the 2MASS, *WISE*, VVV, *Spitzer*, and *Herschel* surveys. Large and small catalogs, as well as papers on individual objects have been systematically cross-identified. The catalog provides Galactic and equatorial coordinates, angular diameters, and chronologically ordered designations, making it simple to assign discoveries and verify how often the objects were cataloged by different authors, search methods, and/or surveys. Detection in a single band is the minimum constraint to validate an entry. About 3200 objects have measured parameters in the literature. A fundamental contribution of the present study is to present an additional ≈7700 objects for the first analyses of nature, photometry, spectroscopy and structure. The present focus is not to compile or determine fundamental parameters, but to provide a catalog uniformly characterizing the entries. A major result is that now 4234 embedded clusters are cataloged, a factor of ≈1.5 larger than open clusters. In addition to cross-identifications in different references and wavelength domains, we also communicate the discovery of 638 star clusters and similar objects. The present general catalog provides previously studied objects and thousands of additional entries in a homogeneous way, a timely contribution to *Gaia*-related works.

Key words: astronomical databases: atlases – astronomical databases: catalogs – astronomical databases: surveys – Galaxy: bulge – Galaxy: disk – Galaxy: halo

Supporting material: machine-readable tables

1. Introduction

The first large catalog of star clusters compiled in the literature including discoveries was that of Collinder (1931), with 471 open clusters (OCs). Alter et al. (1970) and Lyngå (1987) gathered nearly 1000 OCs each. Two databases were developed by collecting OCs and their fundamental parameters: WEBDA (Netopil et al. 2012) and DAML02 (Dias et al. 2002), with ≈1200 and 2167 clusters, respectively. After these first discoveries and taking the importance of investigation of star clusters for the formation and evolution of the Galaxy into account, as well as its kinematics, the studies in the field are rapidly growing.

More recently, Kharchenko et al. (2013) employed a stellar base including 2MASS, and homogeneous analysis tools to obtain parameters for 3006 star clusters and associations. It would be important now to create an overall catalog of star clusters and alike objects (SCAOs) in the Milky Way to homogeneously give previous objects and new entries for photometric and structural analyses. Such catalog should encompass OCs, globular (GC) and embedded clusters (ECs), their candidates and similar classes, such as associations and different types of stellar groups. The search of depopulated OC remnants (e.g., Pavani & Bica 2007) may lead to evolved dynamical stages. This together with low-mass dissolving ECs (Oliveira et al. 2018) are important to understand how stars feed the Galactic field (Lada & Lada 2003). The present catalog (hereafter CatClu) cross-identifies all previous SCAOs and presents newly found ones.

As a byproduct of the present catalog, we give in the Appendix CatKGr, a compilation of stellar groups that did not fit CatClu. Part of them are kinematic groups such as halo streams, e.g., Balbinot & Gieles (2018). An additional byproduct is CatGal given also in the Appendix. It is an updated list of the Local Group galaxies and references to their star clusters and associations, which is a fast developing field. CatGal includes ultra-faint dwarf galaxies (e.g., Drlica-Wagner et al. 2015), some of which were revised to faint halo star clusters, becoming a source of new objects for CatClu. CatClu includes a subcatalog of 640 hereby found clusters and candidates. In Section 2, we describe the data sources. Section 3 describes how the database was constructed. In Section 4, the angular distributions of different object types are discussed. Finally, in Section 5, the concluding remarks are given.

2. Data Sources

In this work, both large (typically more than 1000 entries) and small catalogs were analyzed. Also, small sample papers were taken into account. Catalogs are in general related to specific surveys. Examples are Bica et al. (2003b), Dutra et al. (2003), and Froebrich et al. (2007) with 2MASS, Mercer et al. (2005) with *Spitzer*, and Solin et al. (2012) with UKIDSS. Concerning the ESO-VISTA VVV survey, Borissova et al. (2011, 2014) and Barbá et al. (2015) provided new clusters toward the bulge and central disk, which are as a rule absorbed ones. Lima et al. (2014) found new clusters in the NGC 6357 complex with VVV. Majaess (2013), Camargo et al. (2015a, 2016a) employed *WISE* in their EC discoveries. In the present study, the Aladin Sky Atlas with several surveys therein was used to cross-identify catalogs and individual cluster studies. The main observational aspects for classifying objects are related to morphology. We analyze the central

Table 1
Object Classes and Their Counts

Code (1)	Object Classification (2)	Table (3)	Entries (4)
OC	Open Clusters	3	2912
OCC	Open Cluster Candidates	3	651
OC + OCC	Sum of OPEN CLUSTERS and ALIKE	3	3563
EC	Embedded Clusters	3	4234
ECC	Embedded Cluster Candidates	3	349
EGr	Embedded Groups	3	354
EC + ECC + EGr	Sum of EMBEDDED CLUSTERS and ALIKE	3	4937
lPOCR	loose Open Cluster Remnant Candidates	3	449
cPOCR	compact Open Cluster Remnant Candidates	3	78
lPOCR + cPOCR	Sum of OPEN CLUSTER REMNANT CANDIDATES	3	527
Assoc	Associations	3	470
GC	Globular Clusters	3	200
GCC	Globular Cluster Candidates	3	94
GC + GCC	Sum of GLOBULAR CLUSTERS AND CANDIDATES	3	294
MHC	Magellanic Halos's Clusters	3	33
Ast	Asterisms	3	1154
	Total of individual entries		10978
KGr	Kinematical Groups	4	228
KAs	Kinematical Associations	4	17
KGr + KAs	Sum of KINEMATICAL GROUPS AND ASSOCIATIONS	4	242
DGAL	Local Group Dwarf Galaxies	5	138
NGAL	Local Group Normal Galaxies	5	6
DGAL + NGAL	Sum of LOCAL GROUP GALAXIES	5	144
	Total entries in the database		11367

Note. Candidates correspond to the codes OCC, GCC, and ECC. The EGr class corresponds to looser and less populated entries than ECs (Bica et al. 2003a).

concentration, hierarchical structures, stellar density of the object in contrast to the field, Red, Green, and Blue (RGB) band combinations for stellar colors, and the presence of dust and gas emission. Finally, we estimate central coordinates and angular dimensions. Previous analyses in the literature are also considered.

For an overview of this work, we anticipate in Table 1 the statistics of the derived catalogs in this study (Section 3 and Appendix). Thus, the paper contents can be appreciated by means of the object classifications and their counts. By columns: (1) object class abbreviation, (2) object class, (3) catalog table, (4) population counts.

The electronic version of Table 2 provides the references for the three catalogs in the present work (Tables 3–5). By columns: (1) object class, (2) number of relevant objects extracted from the reference, (3) designation or acronyms, (4) reference code, (5) bibliographic reference. Table 2 includes 792 references, the last 14 are electronic. As examples, we provide comments for the first five entries. Herbig 1 and Manova 1 are two previously overlooked clusters retrieved here as ECs, owing to their related dust emission in *WISE*. Herbig 1 currently has a more recent designation in SIMBAD. Manova 1 is a new entry not present in SIMBAD. This emphasizes the historical and chronological search that we made throughout essentially all of the literature. ϵ Indi, 61 Cyg, Gamma Leo, and Groombridge 1830 are stellar groups named after a representative member. Owing to proximity, they are defined not by their coordinates, but by their heliocentric *U, V*, and *W* velocities (e.g., Eggen 1958). They are stellar groups that do not fit star cluster characterizations. Together with moving groups and streams they are classified as the general term kinematic group (Table 4).

Table 2
References for the CatClu, CatKGr, and CatGal Catalogs

Class (1)	*N* (2)	Name/Acronym (3)	Code (4)	References (5)
EC	1	Herbig 1	103	Herbig (1958)
KGr	2	epsilon Indi, 61 Cyg	1743	Eggen (1958)
KGr	1	Gamma Leo	1737	Eggen (1959)
KGr	1	Groombridge 1830	1738	Eggen & Sandage (1959)
EC	1	Manova 1	3044	Manova (1959)

(This table is available in its entirety in machine-readable form.)

The references in Table 2 include more than 30000 items that were analyzed one by one over 20 years to infer or verify their nature, characterization, and cross-identification. We emphasize that these procedures were carried out essentially independent of SIMBAD. Both archiving approaches in general provide similar object data, except that chronology is not systematic in SIMBAD.

We conclude that Table 2 is a tool in itself with 792 references to inject information into and from the CatClu (Table 3), CatKGr (Table 4), and CatGal (Table 5) catalogs. This large reference set is provided in the electronic table format, and is thus not part of the paper itself references. In the following, we discuss classifications.

2.1. Embedded Clusters, OCs, and Associations

We use Lada & Lada (2003) classification of ECs and OCs. Earlier studies referred to ECs as OCs within nebula and/or dust. Lada & Lada (2003) provided a physical classification taking gas and dust loss in the cluster into account. Concerning morphology and structure of ECs, they distinguish centrally condensed or hierarchical clusters. Ascenso (2018) introduces additional criteria, such as the presence of sub-structures, multiple nuclei, and fractal distribution. All these criteria were applied to the available observational images. In future studies, it would be interesting to break up our EC classification into such sub-types.

Mass-loss processes in the early evolution of ECs, as a rule, dissolves them (Tutukov 1978). In this scenario, OCs are ≈5% of the ECs, which dynamically survive the gravitational potential loss. Recognizing ECs is straightforward by their connection with gas and dust, especially in the IR domain showing dust emission in *WISE*, *Spitzer*, and *Herschel*. We suggest the inclusion of the EC classification in SIMBAD. OB associations are in general extended structures with massive stars that are looser than star clusters and occur along spiral

Table 3
Clusters, Candidates, and Similar Objects

l_G (°) (1)	b_G (°) (2)	α (h:m:s) (3)	δ (°: ′: ″) (4)	D (′) (5)	d (′) (6)	Class (7)	Name/Acronym (8)	Comments (9)	References Code (10)
0.00	−1.30	17:50:43	−29:36:22	4	4	GCC	Minni 40,Minniti 40	based on RR Lyrae, $A_K = 0.46$	3404
0.01	−1.90	17:53:09	−29:54:20	2	1.5	OC	AL 2,Andrews-Lindsay 2, ESO 456-5,MWSC 2734	⋯	213
0.02	−1.43	17:51:17	−29:39:04	1.0	1.0	OC	VVV 51,VVV CL151	prominent	1000
0.02	−1.34	17:50:56	−29:36:39	4	4	GCC	Minni 56,Minniti 56	based on RR Lyrae $A_K = 0.46$	3404
0.03	−0.29	17:46:51	−29:03:47	1.5	0.9	OCC	DB 1,Dutra-Bica 1	⋯	098,126

(This table is available in its entirety in machine-readable form.)

Table 4
242 Kinematical Groups and Kinematical Associations

U (km s^{-1}) (1)	V (km s^{-1}) (2)	W (km s^{-1}) (3)	l_G (°) (4)	b_G (°) (5)	d (°) (6)	D (°) (7)	Designations (8)	Type (9)	Comments (10)	Reference Code (11)
⋯	⋯	⋯	25.39	−18.38	20	10	A 8	KGr	78 M III stars; $d = 92.6$ kpc	3338
−7.6	−27.3	−14.9	⋯	⋯	360	360	AB DOR MGr	KGr	89 stars, $d = 20$ pc rel. to Pleiades?	981, 697, 1730, 1731, 1733, 1732
⋯	⋯	⋯	⋯	⋯	360	360	Acheron Stream	KGr	disrupted GC	1744
20	−20	15	⋯	⋯	⋯	⋯	AFF 7, ZZC 18	KGr	moving group	1722, 1723

(This table is available in its entirety in machine-readable form.)

Table 5
Local Group Galaxies and their Clusters and Associations

l_G (°) (1)	b_G (°) (2)	α (h:m:s) (3)	δ (°:′:″) (4)	d (′) (5)	D (′) (6)	Designations (7)	Type (8)	Comments[a] (9)	Number of SCAOs (10)	Reference Code (11)
5.57	−14.17	18:55:20	−30:32:43	450	216	Sagittarius Dwarf, SagDEG	DGAL	dSphE7	incl 6 GCs	1203, 1220, 1223
11.87	−70.86	23:26:28	−32:23:20	1.8	1.8	UKS 2323-326, UGCA 438	DGAL	dIrr, in NGC55 Gr	⋯	1220
18.9	−22.90	19:52:41	−22:04:05	4	4	Sag II, Sagittarius II[d]	DGAL	GC?, UFF.	⋯	3024
21.06	−16.28	19:29:59	−17:40:41	2.9	2.1	Sagittarius Dwarf Irr.[b]	DGAL	dIrr IB(s)	⋯	1220
25.34	−18.40	19:44:57	−14:47:21	15	14	NGC 6822, IC 4895[c]	DGAL	dIrr, inc 6 GCs	47 young Cls	1220, 3342, 3353

Notes.
[a] The electronic table contains in addition the distance and absolute magnitude.
[b] Other designations: ESO 594-4, SagDIG, UKS 1927-177.
[c] Other designations: DDO 209,Barnard's Galaxy.
[d] Additional designation: Laevens 5.

(This table is available in its entirety in machine-readable form.)

arms (Ambartsumian 1955). R associations are groups of reflection nebulae, themselves sites of star formation (Herbst & Racine 1976). T associations are star-forming stellar groups in a stage that contains many T Tauri stars (Ambartsumian 1957). Associations sometimes present subassociations (Mel'Nik & Efremov 1995). HIPPARCOS organized nearby associations by means of positions, proper motions (PMs) and parallaxes (de Zeeuw et al. 1999), while *Gaia* will have a fundamental role in the definition of associations beyond our neighborhood. The present study collected, cross-identified, and condensed them into 470 associations (Table 1), which are provided in Table 3 with the respective references (Table 2). Since massive ECs can also become unstable and dissolve, they may contribute to the development of associations (Saurin et al. 2012 and references therein).

2.2. Cluster Remnants and Candidates

Poorly populated stellar concentrations can turn out to be OC remnants, or field fluctuations, when studied by means of color–magnitude diagrams (CMDs) and other means (e.g., Carraro 2000; Odenkirchen & Soubiran 2002; Pavani & Bica 2007; Pavani et al. 2011). We have suggested two criteria to observationally define the candidates: (i) poorly populated stellar concentrations, and/or (ii) stellar surface density variations along the cluster position angle on the sky (Bica et al. 2001). The loose Possible Open Cluster Remnants (lPOCR) are very common (Table 1). We also provide an updated list of compact Possible Open Cluster Remnants (cPOCR), which are rarer (Pavani et al. 2011). The former are expected to be dynamically evolved OCs, and the latter fossil cluster cores (Bica et al. 2001). Recently, some dynamically advanced OCs have been proposed by Angelo et al. (2018) and further support evolutionary connections.

2.3. Asterisms

Asterisms are stellar configurations or concentrations that are not expected to be star clusters or associations. Many have been identified by amateur astronomers, often with telescopes or in DSS. Under close scrutiny, some of them turned out to be star clusters (Dias et al. 2002; Bica & Bonatto 2011). Their classification also encompasses poorly populated stellar concentrations that the literature showed not to be star clusters (e.g., Odenkirchen & Soubiran 2002; Pavani et al. 2011). Datamining the asterisms in Table 3 and analyzing them with photometry and PMs, in particular with *Gaia*, will certainly reveal a number of new interesting clusters. The amateur astronomer group Deep Sky Hunters searched for star clusters especially on DSS images and provided many candidates that were confirmed to be clusters (Kronberger et al. 2006; Bonatto & Bica 2010). Table 1 indicates 1154 asterisms which are listed in Table 3. Several lists are available in the WEB, and others were deactivated. Such lists were made by amateur astronomers. One of us (E.B) collected them during ≈1 decade preserving the original designations, and inspected images with Aladin. Density contrast, richness, and relation (or not) to gas and dust were taken into account (Table 3). Table 2 shows 14 electronic references mostly concerning asterisms. An example of a currently active list in the WEB is Ferrero's with 53 entries. The largest list was compiled by B. Alessi with 1070 entries as given in DAMLO2.

2.4. Designations

Historical designations like NGC and IC are easy to remember. In the 20th century, an author's last name was usually employed for OCs (e.g., Trumpler, Markarian, or Melotte), or the institute (Harvard), see Collinder (1931). In the 70s, the IAU and C acronyms followed by B1950.0 equatorial coordinates were proposed for star clusters, but became obsolete with J2000.0. Acronyms formed by the author's last name initial letter(s) are usual since the last decade of the 20th century (e.g., FSR Froebrich et al. 2007). Recently, the acronym MWSC (Milky Way Star Cluster) was employed by Kharchenko et al. (2013). Technical designations at times given in SIMBAD are complex, with author(s) last name initial letter (s) and the year within brackets, followed by an ordering number, J2000.0 equatorial, or Galactic coordinates. They are an important option for archiving purposes because they are unique among all classes of astronomical objects. A disadvantage is their complexity which may lead either to usage simplifications or alternatively, doom an object to oblivion. The present catalog adopts all designations which are commonly used in papers, and are unique within the star cluster and association areas. Additionally, some options must be established. Dias et al. (2002) adopted up to two author last names. We rather adopt a single author name, and initial last name letters for two or more authors (see the case of AL 2, the second entry in Table 3). Recently, Minniti et al. (2017b) employed the first author name as acronym. This is consistent, if a given author searched himself for new objects in a survey. In their recent new sample of 84 GC candidates, they also suggested a shorter acronym (Minni), for simplicity in papers. Accordingly, we suggest the use of the acronym Bica for the objects hereby discovered (Section 3.2). We recall that the OCs Bica 1 through 6 were so designated by Dias et al. (2002). We suggest Bc, for short.

The VVV survey has produced numerous new clusters (e.g., Borissova et al. 2011, 2014; Barbá et al. 2015) with designations in terms of VVV-CL and La Serena. With the advent of the VVVX survey surrounding that of VVV, discoveries can be designated as VVVX-CL or VVVX for conciseness. In the case of VVVX, the present catalog will be a fundamental tool for unambiguous new discoveries.

3. Catalog Construction

As a previous experience, Bica & Schmitt (1995) and Bica et al. (1999) provided deep catalogs of the LMC and SMC-Bridge SCAOs, with 6659 and 1188 entries, respectively. They made cross-identifications using ESO/SERC Red and J (Blue) films. Bica et al. (2008) updated them to 9305 entries. The acquired experience by one of us (E.B.) in the Clouds was fundamental to collect and analyze SCAOs counterparts in the Galaxy. Together with the clusters and candidates in the literature, new ones were systematically cross-identified and eventually became discoveries.

3.1. A Multi-band Catalog

Wavelength ranges of the surveys and their RGB color compositions became wider with time. Optical and IR survey bands became available in the Aladin and IPAC tools in subsequent upgraded versions. This multi-band study expanded from the early DSS to the near-IR employing 2MASS and VVV, and further to the mid and far-IR with *WISE*, *Spitzer*, and *Herschel*.

The approach follows previous catalogs and cluster analyses. Examples are the cluster candidates probed with 2MASS toward the bulge and central disk (Dutra & Bica 2000), together with one of the first cluster general catalogs in the near-IR (Bica et al. 2003a), and samples for detailed studies of CMDs and structure (e.g., Bonatto & Bica 2009).

To date, taking into account WEBDA, DAMLO2, and MWSC (Kharchenko et al. 2013; Schmeja et al. 2014) about 3.200 objects have astrophysical parameters. We analyzed them together with several thousand new ones in a homogeneous way. We note that a single cluster identification in a given band is enough to be included in the catalog. This stems from the properties of a cluster and its line of sight, such as absorption, richness, age and distance, as well as observational and instrumental conditions such as seeing, pixel size, crowding, and limiting magnitude of a given survey.

To illustrate the meaning of the multi-band analysis, we give in Figures 1–3 examples of band combinations into RGB colors for three newly found objects (Section 3.2). The images of the surveys were obtained in Aladin version 9.0. The DSS color atlas (hereafter CA) uses the *B, R* and *I* bands. The 2MASS CA employs the *J* (1.24 μm), *H* (1.66 μm) and K_s (2.16 μm) bands. The VVV CA combines near-IR bands and we connected it to Aladin 9.0. The *WISE* CA includes the *W4* (22 μm), *W2* (4.6 μm) and *W1* (3.4 μm) bands, and is sensitive to stars and dust emission. The *Spitzer* CA consists of a set of bands from 3.6 μm (IRAC1) to 8.0 μm (IRAC4). *Herschel* uses the 70 μm and 100 μm bands for a BR color composition representing ESA's Photodetector Array Camera and Spectrometer (PACS) CA, which is sensitive to relatively cold dust emission and dust caps around YSOs. The DSS, 2MASS and *WISE* surveys generated all-sky atlases. VVV is dedicated to the bulge/

Figure 1. Color extractions of 8′ × 8′ for the OCC Bc 105. North to the top, east to the left. Mosaic images from left to right are from DSS, 2MASS, and *WISE*.

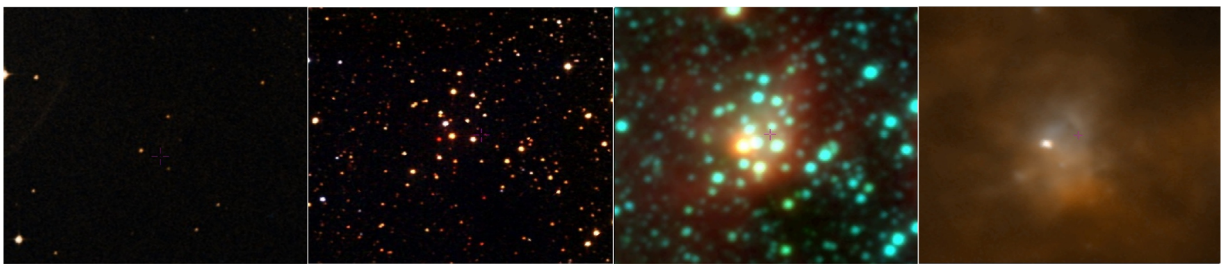

Figure 2. Color extractions for the EC Bc 74 corresponding to DSS, 2MASS, *WISE*, and *Herschel*. Angular dimensions and orientation as in Figure 1.

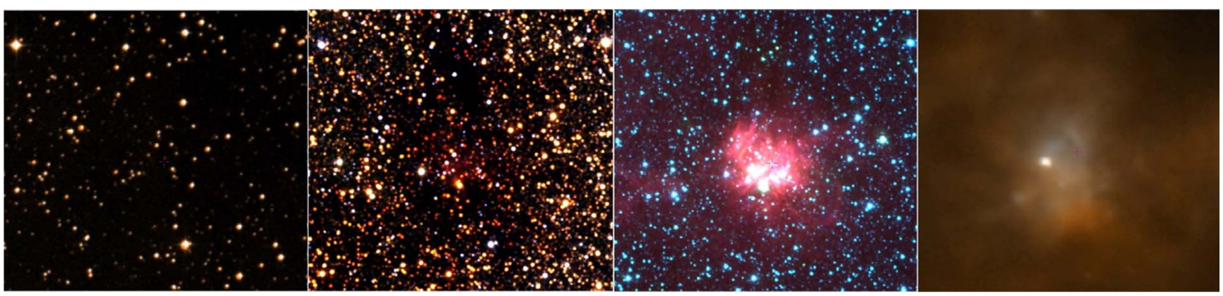

Figure 3. Same as Figure 2, except for the third panel, which is from *Spitzer*, for the deeply embedded cluster Bc 37.

central disk region, while *Spitzer* and *Herschel* have particular coverages, especially along the disk.

Figure 1 shows the new OC candidate (OCC) Bc 105. In the optical with the DSS RGB, it is not detected owing to contamination and absorption effects. It shows up in the near-IR with 2MASS. In the mid IR (*WISE*), it shows no dust emission, as expected for an OC. Possibly, many of the new OCCs will require analyses with deeper photometry than 2MASS.

Figure 2 shows the EC Bc 74 (Ryu 265—see Section 5), which is invisible in DSS owing to high absorption. In 2MASS, it becomes a conspicuous cluster. Many clusters from Froebrich et al. (2007) present this behavior. Dust emission shows up in *WISE*, revealing an associated EC. It also shows cold dust emission in the far-IR (*Herschel*).

Figure 3 shows the EC Bc 37 (Ryu 675). It is undetected in DSS and very contaminated in 2MASS. *Spitzer* reveals a prominent deeply embedded EC with diffuse dust emission and dust-capped YSOs. Finally, *Herschel* shows strong cold dust emission.

Table 4 deals with kinematical groups and kinematical associations. The latter are nearby young stellar groups that may cover large solid angles in the sky, or even have an all-sky distribution, if the Sun is located within their volumes (e.g., the Local Association—Zhao & Chen (2009). Table 5 compiles Local Group galaxies and indicates their star cluster and association content.

The classification scheme in itself is for the first time presented in the literature concerning a general catalog. The first approach is to adopt the original author's classification, but in dubious cases, we re-analyzed the object by means of morphological properties (Section 2.1) in images and the available information in the literature. When a new result supersedes the original classification(s), we adopted it, e.g., the case of five cluster remnant candidates that four of them turned out to be asterisms with *Gaia* (Kos et al. 2018).

3.2. The Subcatalog of Newly Found 638 Entries

During the last 20 years, many new SCAOs were identified in the surveys by one of us (E.B.). A number of them have in the mean time been published by other authors, and were excluded. We ended up with 661 new objects. They were subsequently merged into CatClu. ECs are frequent in this list owing to evident dust emission in *WISE* (Camargo et al. 2015a, 2016a), as well in *Spitzer* and *Herschel*, when available. The discoveries amount to 638, because 23 are in common with Ryu & Lee (2018a)—see Section 5.

3.3. The CatClu catalog

We retrieved the chronological order of publications in the literature. Re-discoveries are not a demerit because new detections of a given object will support its existence, in particular if it shows up in different wavelength ranges. The electronic version of Table 3 shows star clusters, candidates and alike objects. By columns: (1) and (2) Galactic, (3) and (4) J2000.0 equatorial coordinates, (5) and (6) major and minor diameters in arcmin, (7) classification code, (8) chronologically ordered cross-identified designations, (9) long field for comments, and (10) reference code.

Some of these class samples have increased dramatically, in particular ECs, lPOCRs and asterisms. Cataloging SCAOs dates back to at least two centuries with Messier's list. CatClu shows small and/or fainter clusters, in general more absorbed than larger more populated classical ones in WEBDA, DAMLO2, and MWSC. The former two deal with OCs with parameters collected from the literature. MWSC derived parameters for 3006 OCs, GCs and associations. However, they analyzed additionally 778 objects that were considered to be (i) not a cluster, (ii) possible cluster but parameters not determined, and (iii) duplications. We checked all these classifications and incorporated them to the catalog. We agree that many are not clusters or alike, but a considerable fraction is of embedded clusters owing to the dust emission now seen in *WISE*, *Spitzer* or *Herschel*.

Vizier provides catalogs but does not cross-identifies them, and does not deal with small samples or individual clusters in papers. SIMBAD shows cross-identifications but in general does not consider chronology. The present work overcomes these limitations. This multi-band survey (Section 3.1) is a powerful tool to revise, detect and classify objects in the optical and IR. We also find and/or compile poorly populated objects like compact and loose POCRs (Pavani & Bica 2007). They are a fundamental sample to be explored, probably dealing with aspects of cluster dynamical evolution and dissolution. The present catalog is both a base of objects for *Gaia* and a database for further developments in SIMBAD and Vizier. Some ECs seen in *WISE* and *Spitzer* are so much absorbed that they are not expected to be in *Gaia*. A discussion on angular distributions of different object classes and their total populations is provided in Section 4. Table 1 shows that to date ECs outnumber OCs. The analyses of asterisms may reveal a number of star clusters. In particular, we detected several ECs among the asterisms. About 7700 entries in CatClu require first studies.

We emphasize that such entries are not only cluster candidates. According to Table 1 we have important populations of e.g., OCCs, ECCs, and GCCs. Thus, our classification is a step further in terms of class discrimination. It is important to remark that for some authors a cluster only becomes so after astrophysical parameter determination. As a consequence, there are many obvious clusters (identified morphologically) that are not studied in terms of astrophysical parameters; e.g., among the 4234 ECs, only a few hundred have parameters.

3.4. Our Group Contributions

Our group contributions to the general catalog started as lists developed with 2MASS, e.g., Dutra & Bica (2000) with 58, Dutra et al. (2003) with 179, and Bica et al. (2003b) with 167 entries. More recently, Camargo et al. (2016a) and references therein provided 1101 entries, mostly ECs found in *WISE*. Several of our studies included a few clusters. In all, we published 28 papers contributing with 2336 entries (21%) of Table 3. Taking into account cross-identifications and chronological ordering of designations, our group has discovered ∼20% of CatClu. In addition, two of us (C.B. and E.B.) collaborated in cluster lists of the VVV Survey (Borissova et al. 2011, 2014). Finally, Bica et al. (2003a) compiled ECs and embedded groups from the IR literature, which are now incorporated in Table 3.

4. Angular Distributions and Statistical Properties

Statistical properties of the object sample and subsamples are considered using angular distributions of the object types. We employ: (i) Galactic coordinates $l_G \times b_G$ in Aitoff projections for a selection of object types in CatClu; (ii) b_G distribution functions to compare the overall structures; (iii) number-density maps to check for internal structures. Figures 4–12 do not include the new discoveries in the literature, because they have an impact essentially in the central parts (Section 5).

Figure 4 shows the large EC sample compared to OCs. The bulk of the ECs is more tightly distributed to the plane. Some ECs are projected at intermediate latitudes and a few appear to be related to gas and dust halo clouds (Camargo et al. 2015b, 2016b). The bulk of OCs attains higher latitudes than that of ECs and may suggest that OCs often become dynamically heated with time. Alternatively, they might acquire their orbital properties preferentially at birth in the plane.

Figure 5 shows the lPOCR sample superimposed on OCs. The distributions are similar, although the lPOCRs attain on the average somewhat higher latitudes (Figure 9). However, the overlapping region suggests that OCs and POCRs appear to be statistically related, supposedly in terms of evolutionary terms.

Asterisms (Figure 6) are more widely distributed in b_G than OCs. The fraction of the distribution in common suggests the presence of physical objects in the asterism sample, while the high-latitude excess might imply contamination of chance stellar concentrations.

The GC population has recently had an important progress (Figure 7). Bica et al. (2016) have decontaminated the bulge of halo intruders. The confirmed population is about to reach 200 GCs (Minniti et al. 2017a). GCCs in the bulge area have also increased, especially in the VVV area (Minniti et al. 2017b). The bulge GCs are strongly concentrated to the center, while the halo ones populate most of the celestial sphere at low densities.

Several GCs trace the Milky Way outer halo beyond 100 kpc (Harris 2010). The LMC and SMC cluster systems, with heliocentric distances of 51 and 64 kpc (McConnachie 2012), respectively, are currently enclosed in the Galactic halo. SMC and LMC halo clusters are detached from their respective main bodies (Bica et al. 2008). Recently, the clusters SMASH 1 (Martin et al. 2016), *Gaia* 3, Torrealba 1, DES 4 and DES 5 (Torrealba et al. 2018) were detected in the LMC halo, while Tuc V is probably a cluster or remnant far in the SMC halo. All

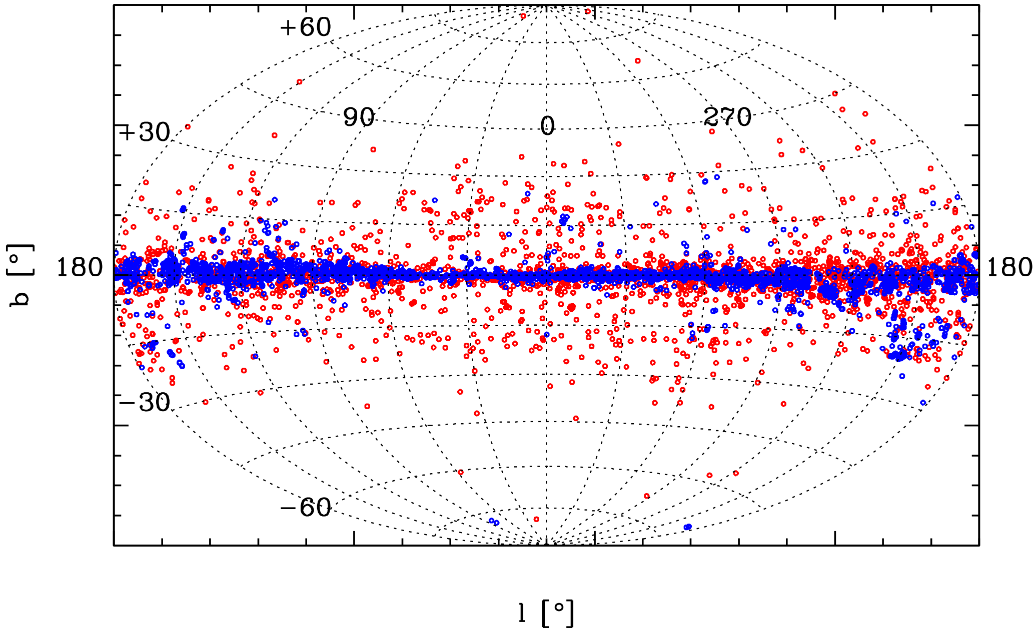

Figure 4. Aitoff projection for the ECs (blue circles) compared to OCs (red circles).

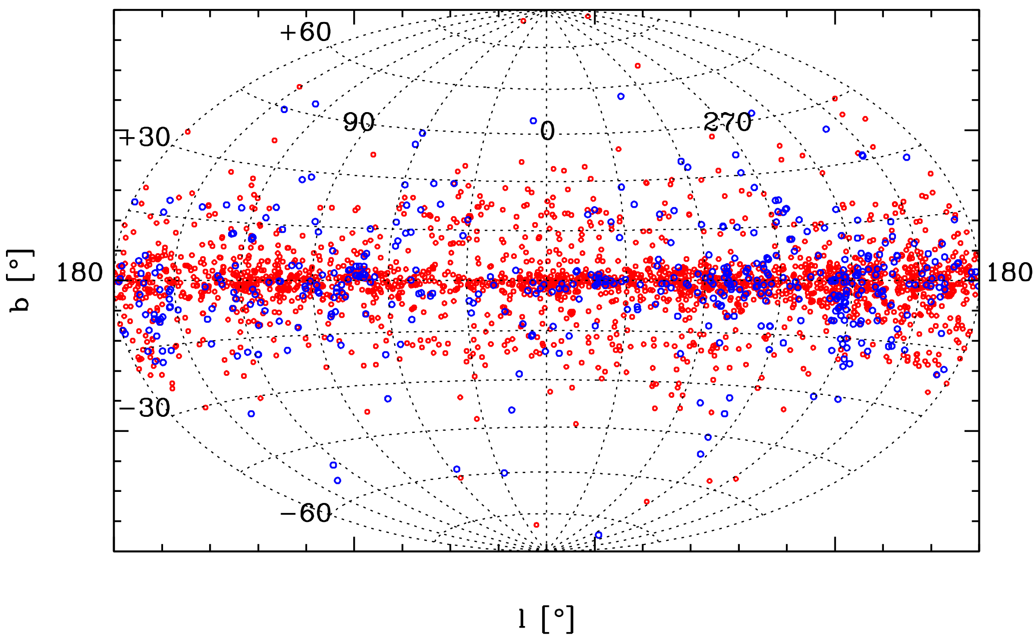

Figure 5. Same as Figure 4, but for lPOCRs (blue circles) compared to OCs (red circles).

outlying LMC clusters in Sitek et al. (2016) are projected on the LMC disk, while eight SMC outliers in Sitek et al. (2017) can be classified as SMC halo's. Such clusters (Figure 7) may be eventually accreted by the Milky Way, and thus we introduce the Magellanic Halos's Clusters (MHC) class in Tables 1 and 3. The interaction between the LMC and SMC led the SMC to tidal stripping (Dias et al. 2016), favoring the occurrence of SMC halo clusters. The SMC now has 22 and the LMC 11 cataloged clusters in their halos, and the angular distribution is given in Figure 7. We point out that in the present census we exclude young clusters related to the tidal Bridge that connects the Clouds (Bica et al. 2008, 2015). At any rate, they populate the Galactic halo with a young stellar component.

The total star-forming sample (Figure 8) has a narrower distribution than the evolved one. The former distribution also decays fast for $|b_G| > 35°$. This clearly shows how the projected star formation is concentrated to the plane. A small local excess occurs especially in the evolved sample at $|b_G| \approx 20°$. Such features may correspond to changes in the OC population (Corrêa de Aguiar 2017).

It is remarkable how all star-forming subsamples present essentially the same $|b_G|$ distribution (Figure 9), which tend to form near to the plane. OCs and the large sample of OCCs have comparable widths, suggesting that the OCCs are worth data-mining for OCs. Finally, POCRs depart somewhat from OCs, and asterisms depart yet more. However, both POCRs and asterisms overlap major fractions of their distributions with OCs, again indicating the need of data-mining.

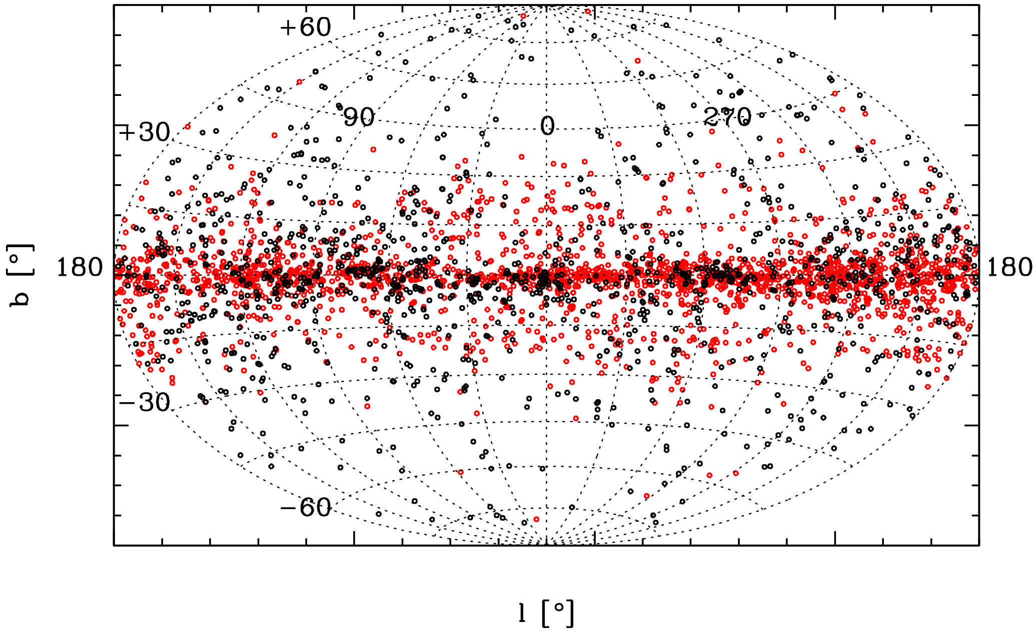

Figure 6. Same as Figure 4, but for asterisms (black circles) compared to OCs (red circles).

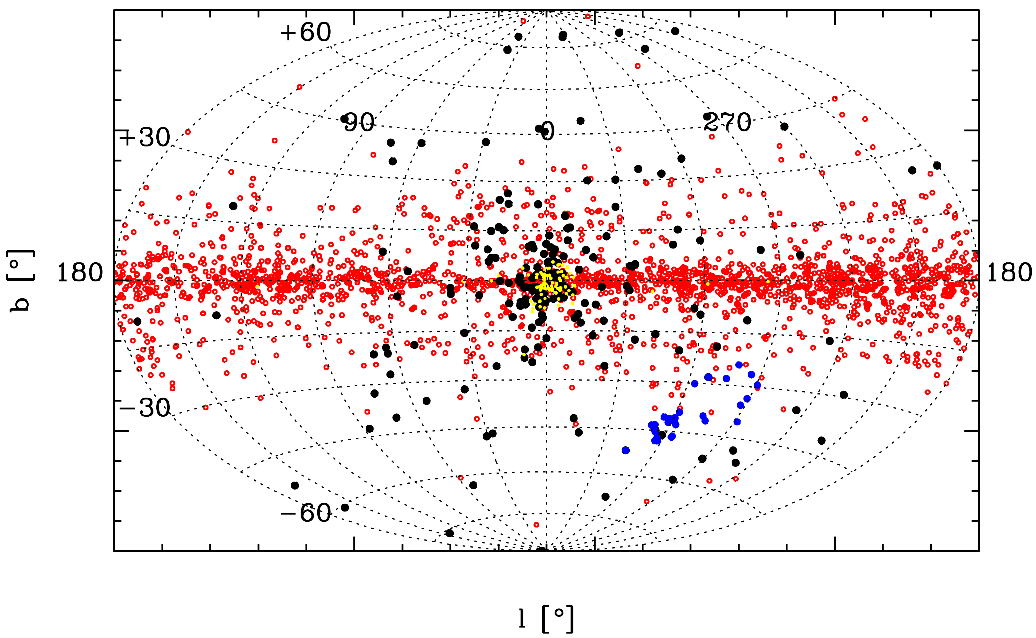

Figure 7. Same as Figure 4, but for GCs (black dots) and GCCs (yellow dots), compared to OCs (red circles). Also shown are MHC clusters (blue circles).

Figure 10 shows the Galactic warp for $|l_G| < 100°$, together with the disk flares for $|l_G| > 100°$ (Momany et al. 2006 and references therein). The warp is clearer in the EC sample (Figure 11), together with a flare effect.

In the OC distribution (Figure 12), a series of small overdensities occurs along the plane. They have some counterparts in the Galactic spiral arms and their tangent points (Vallée 2017). Tangent points imply line-of-sight accumulation of H I, H II, dust, and young clusters. The occurrence of excesses in tangent points might be explained by non-embedded young clusters in the range 10–50 or even as old as 100 Myr. We caution for the possibility of over or undersampled zones, since the results stem from many authors. Nevertheless, the present cross-identifications minimized such effects.

5. Concluding Remarks

The present work was carried out essentially in an independent way of SIMBAD. This was achieved both for cross-identifications of large lists, such as FSR (Froebrich et al. 2007) and MWSC (Kharchenko et al. 2013), and individual object papers. It would be important to keep the present SCAO catalog undismembered in VIZIER and/or CDS.

It would also be important that SIMBAD incorporates the present results taking into account the unique efforts employed here to identify and characterize SCAOs, and shed light in cases of doubt.

We further stress the importance of the different object classes, from ECs, through OCs to remnant candidates (Bica et al. 2001; Pavani et al. 2011). Different evolutionary paths

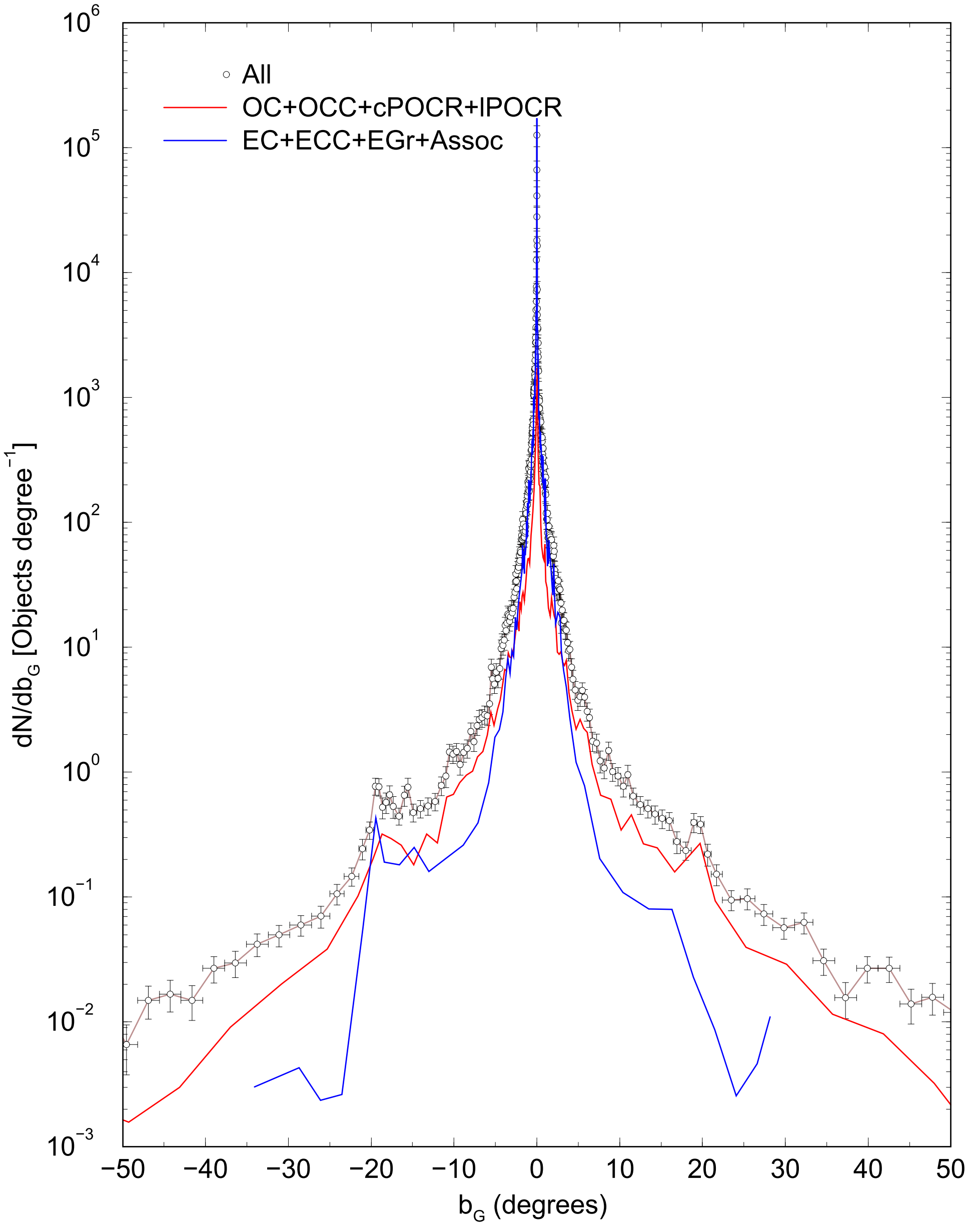

Figure 8. Galactic latitude (b_G) distribution functions normalized for peak value. Star-forming samples (EC+ECC+EGr+Assoc) compared to evolved ones (OC +OCC+cPOCR+lPOCR), and with the overall sample (excluding asterism and MHCs).

can connect them both photometrically and structurally. In particular, ECs can dissolve, never evolving to OCs (Lada & Lada 2003), and they might produce as well young cluster remnants. On the other hand, asterisms have proven to be very useful for data-mining (Bica & Bonatto 2011).

The number of GCs and candidates in the MW has increased dramatically to 294 (Tables 1 and 3) as compared to the 157 GCs listed by Harris (2010). This progress was achieved mostly by studies unveiling the low-luminosity bulge GCs, e.g., Minniti et al. (2017b), Piatti (2018), Bica et al. (2018), and Camargo (2018). Considering the MW GC candidates, this can potentially alleviate the MW count deficiency with respect to M 31, with 361 GCs in the sample of Caldwell & Romanowsky (2016) and the total estimate of ≈450 by Larsen (2016), recalling that the MW and M 31 appear to present comparable masses (Phelps et al. 2013).

SIMBAD has been successful in cross-identifications of point sources like stars among many catalogs, since they are more suitable for automated tools. Diffuse distant galaxies close to the point-source limit are likewise well suited for cross-identifications among large databases e.g., SIMBAD and the NASA Extragalactic Database. On the other hand, SCAOs are extended, sometimes angularly large, with low surface brightness variations owing to stellar depletions, contamination, absorption and distance effects, as well as dependent on observational and instrumental conditions in a given survey. They may show neighbors or hierarchical distribution. Care is necessary in handling them. Automated searches of overdensities have provided new clusters. Automated analyses of CMDs and cluster structure have given, in turn, fundamental parameters (Kharchenko et al. 2013). Samples detecting new clusters by searching overdensities and deriving their

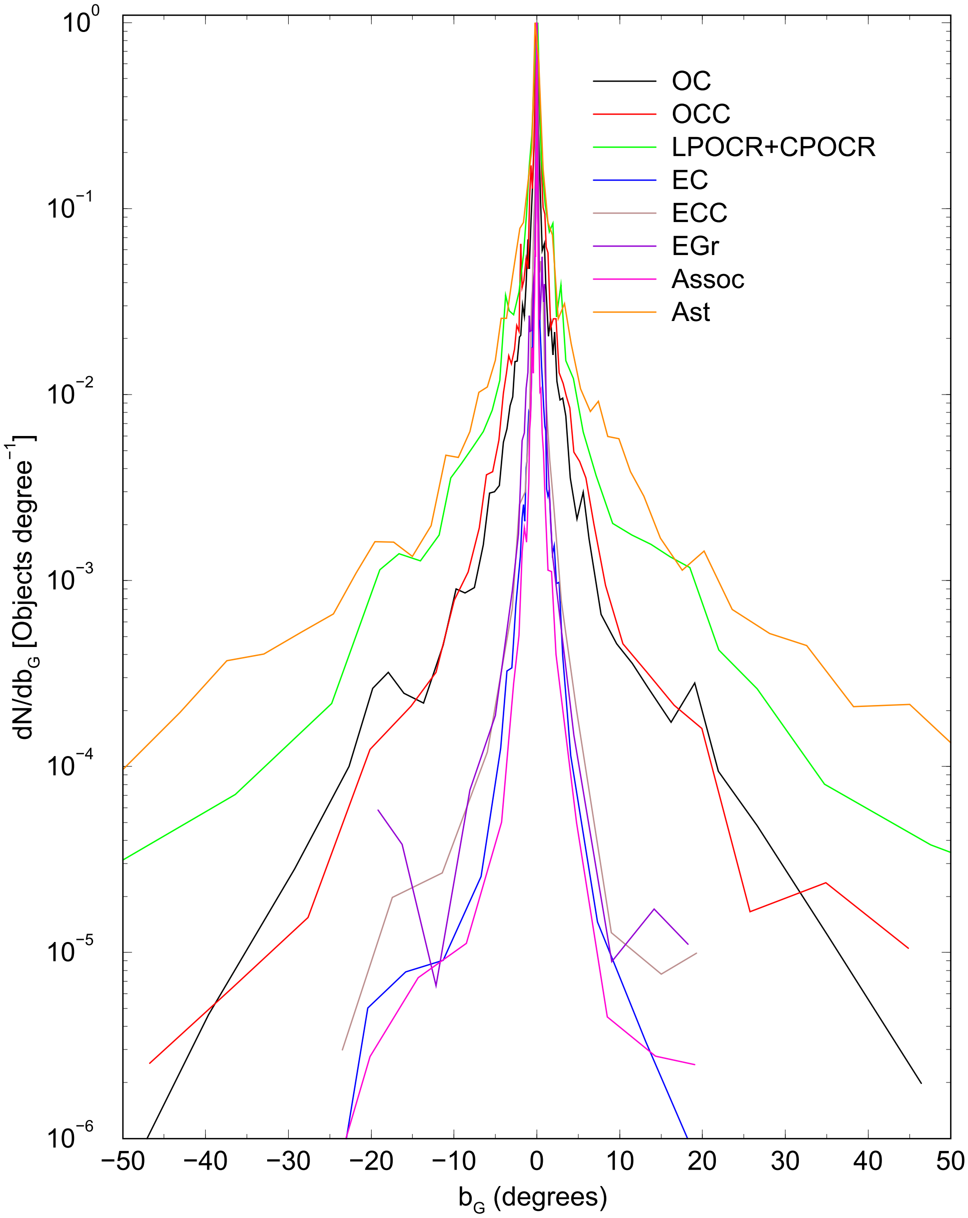

Figure 9. Same as Figure 8, but for individual samples.

parameters were recently obtained (Schmeja et al. 2014; Oliveira et al. 2018).

Awaiting for automated future searches and analyses in any survey environment, the present work has carried out the task of homogeneously organizing all previously available and new SCAOs into a single database. It furnishes a collection of several thousand fresh objects for photometric and spectroscopic studies, as *Gaia* unveils parallaxes and PMs (Gaia Collaboration et al. 2017). We have developed a database of 3 catalogs: (i) clusters, candidates and alike objects (Table 3), (ii) kinematic groups and kinematic associations (Table 4), and (iii) Local Group galaxies and their star clusters and associations (Table 5). These catalogs share the same list of 792 references. Table 3 with 10,978 star clusters and candidates outnumber by several thousands the entries in any previous catalog or database.

Gaia will give precise parallaxes, PMs and photometric measurements for several hundred nearby OCs, providing essential constraints to stellar evolution models (Gaia Collaboration et al. 2017; Randich et al. 2018). For star clusters and stellar groups with increasing distance from the Sun the three-dimensional distribution of different cluster generations will be obtained, and within uncertainties, probably that of the entire near side of the Galaxy. Undoubtedly, the present effort, with thousands of entries more than any previous catalog or database, is a timely contribution to *Gaia*.

As this work approached completion, two papers with *WISE* (Ryu & Lee 2018a, 2018b) and two others with *Gaia* DR2 (Beccari et al. 2018; Castro-Ginard et al. 2018) data have been published with new discoveries that add to the present work. Concerning both *WISE* results, the authors have discovered hundreds of new clusters, most of them non-embedded, including two new Globular clusters. The *Gaia* works represent the first wave of discoveries with *Gaia* DR2 (Gaia Collaboration et al. 2018). In this context, the present work is a valuable tool to minimize re-discoveries and facilitate the search and

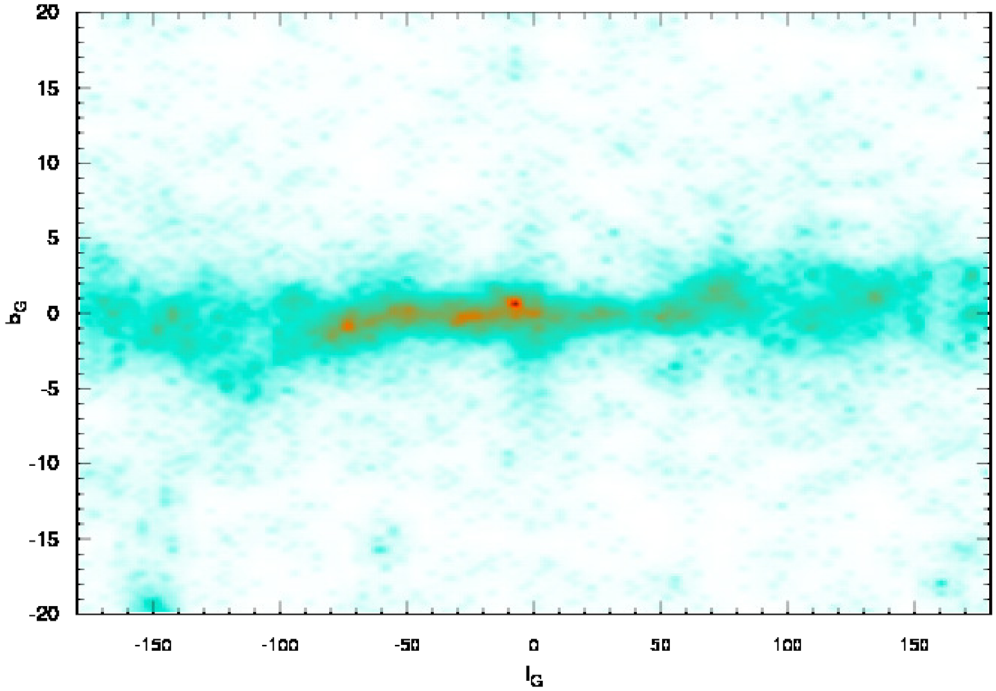

Figure 10. Number-density map (in Galactic coordinates) of the total sample (excluding the asterisms).

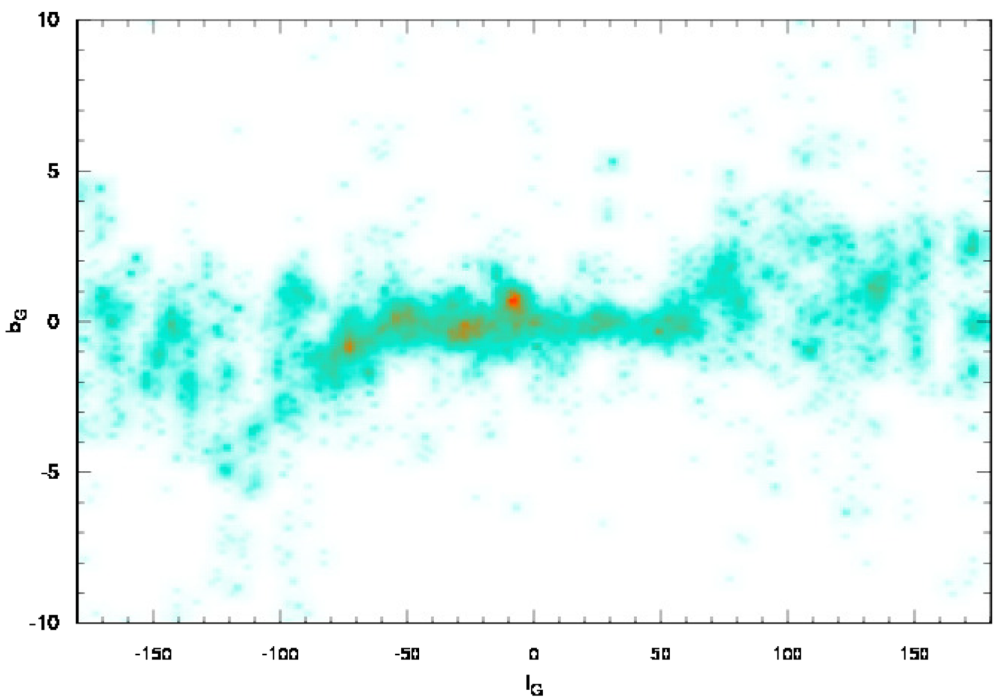

Figure 11. Same as Figure 10 for the EC sample, thus enhancing the warp and flare.

identification of targets. Finally, we remark that the new discoveries above have been fully cross-checked and the new ones incorporated into the catalog. The already existing objects were indicated as equivalent in the list of designations in the respective catalog.

Given the accuracy of the coordinates in the present catalog, as well as those in Ryu & Lee (2018a) for 921 clusters (202 ECs and 719 OCs), we applied for the first time in this study a position matching routine. For separations larger than 120″, the catalogs have no objects in common for 848 clusters, which are thus new. The catalogs match for 73 clusters: (i) we confirm 24 as additional new clusters as a rule in pairs, while (ii) 26 coincide with the previous literature, and finally, (iii) 23 are equal to clusters found by one of us (E.B.—the present Bc clusters), including Ryu 265 = Bc 74 (Figure 2), Ryu 675 = Bc 37 (Figure 3). Thus, in Table 3 we assigned them Ryu as the first designation, since the publication date establishes a discovery (Section 2.4). The Bc designations were maintained in Table 3, as well as in Figures 2 and 3, as additional ones, in the sense that detections by different authors

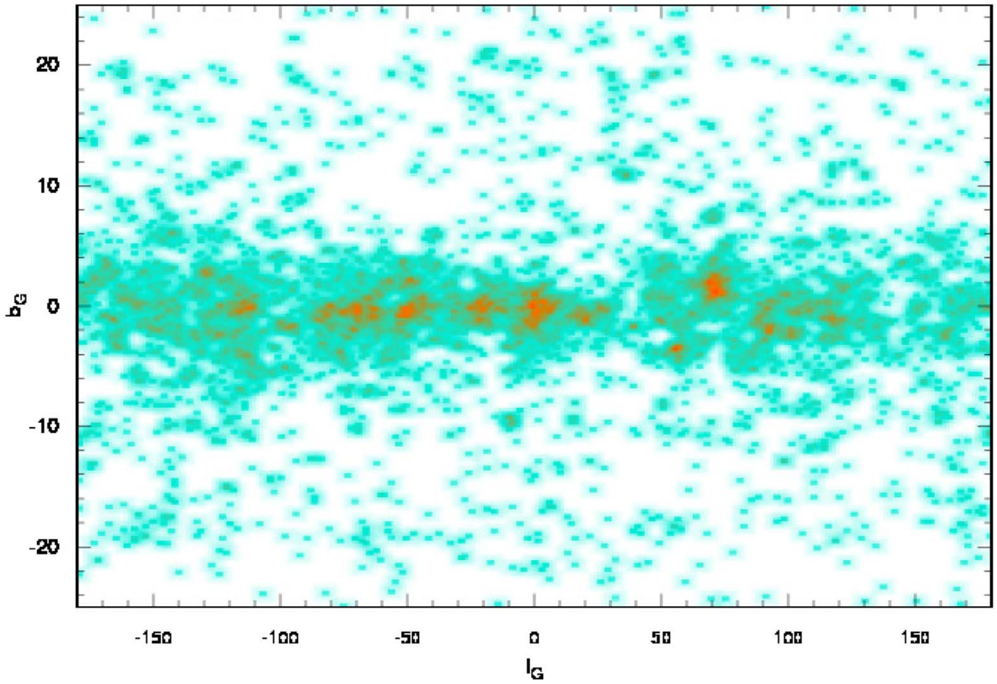

Figure 12. Same as Figure 10 for the OC sample, showing overdensities.

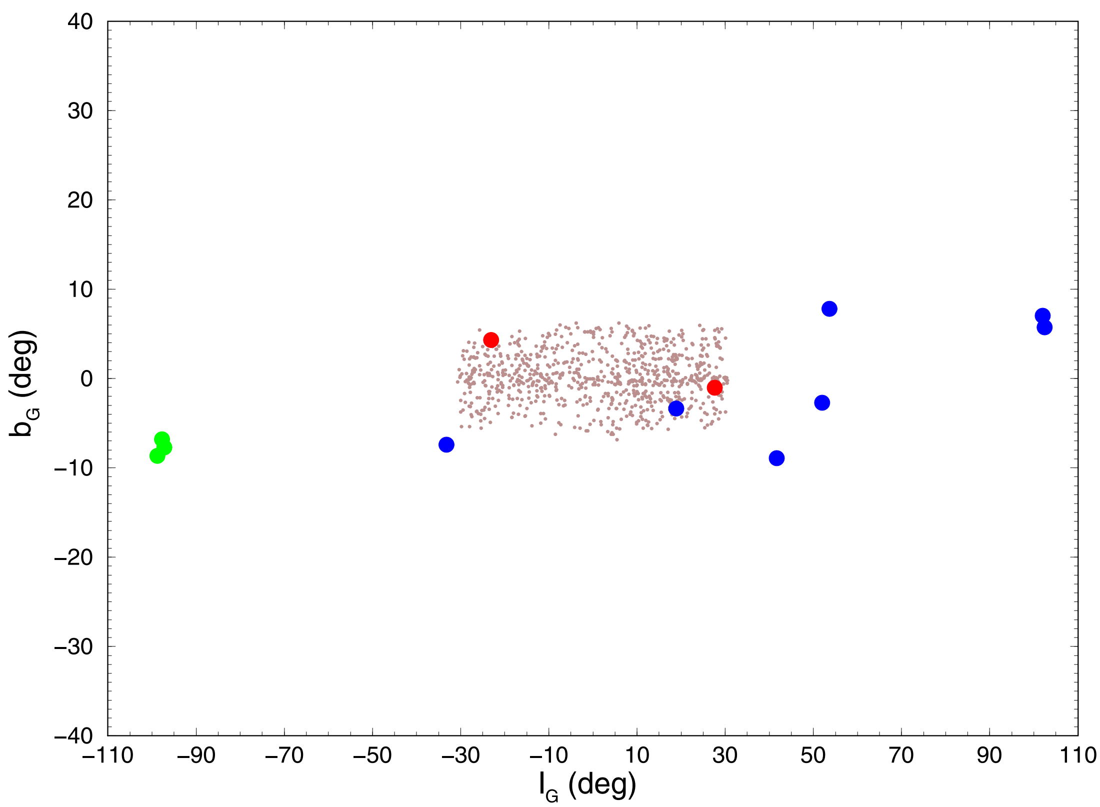

Figure 13. The recent additions from literature: Ryu & Lee (2018a) (brown symbols); the 2 new GCs of Ryu & Lee (2018b) (red circles); Beccari et al. (2018) (green circles); Castro-Ginard et al. (2018) (blue circles).

give more weight to a given cluster. The new additions are shown in Figure 13. The *Gaia* discoveries so far deal with nearby clusters along the disk, while the *WISE* sample roughly corresponds to a rectangular distribution in the central parts. We checked the impact of the new objects on Figures 11 and 12, finding that the central sample produces a slight enhancement of the structures in both figures. The rectangular shape (Figure 13) persists for OCs, but essentially merges into the EC sample.

A website containing the present database will be made available soon. We emphasize that the online database will be updated as new entries appear.

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Appendix
Galactic Kinematical Groups and Clusters in Local Group Galaxies

Two additional catalogs were compiled in this work: (i) 242 kinematical groups (CatKGr, Table 4), and (ii) 144 Local Group galaxies and their cluster and/or association content (CatGal, Table 5). CatKGr shows objects that do not fit OC characterizations, such as moving groups, and the fast growing domain of halo streams. CatGal provides references to star clusters and associations in Local Group (LG) galaxies. It also includes the ultra-faint galaxies (UFGs) that deeper studies may reclassify some of them as faint halo clusters (FHC), thus supplying CatClu with additional entries. The present catalogs form an interwoven database for future studies. The electronic version of Table 4 (the first five lines are shown) compiles the kinematical entries. By columns: (1) to (3) *U, V* and *W* heliocentric velocities, (4) and (5) Galactic coordinates, (6) and (7) large and small angular diameters, (8) designation(s), (9) type, (10) comments, (11) reference code(s).

CatKGr deserves an updated catalog owing to many recent studies, especially halo streams and their occasional connection to former star clusters (Balbinot & Gieles 2018). CatGal gathers the recent discoveries of underluminous Milky Way satellites (e.g., Drlica-Wagner et al. 2015; Koposov et al. 2015a). Some follow-up studies have reclassified a few as FHCs (e.g., Conn et al. 2018). Another reason to update Table 4 is the growing number of compilations and new detections of star clusters and associations with deep surveys (e.g., 1249 young clusters in M31 Johnson et al. 2016). CatKGr objects are characterized by heliocentric velocities and/or Galactic coordinates, or simply by designation and reference. If the Sun is spatially located within an object, then it becomes an all-sky object distribution. The halo streams are in general related to dissolved galaxies or globular clusters.

The electronic version of Table 5 shows normal, dwarf spheroidal, low-luminosity star-forming, and UF galaxies. We adopted as initial catalog McConnachie (2012)s with 94 entries. More recently, a number of faint halo galaxies were found. The number of galaxies in Table 5 increased LG entries to 144 (53%). Part of the UFGs cannot yet be certified as such, or as FHC, since the diagnostic diagram Mv versus half light radius overlaps them in part. The available classifications are sometimes ambiguous. Sakamoto & Hasegawa (2006) could not distinguish the overdensity SDSS J1257 + 3419 as a dwarf galaxy or a globular cluster, but Belokurov et al. (2007) classified it as a the galaxy CVn II. Mass-to-light ratios in the range 500–600 (Koposov et al. 2015b) derived from velocity dispersions, e.g., for Reticulum 2 or Horologium 1, indicate dark matter domination, and thus a galaxy classification. Such follow-up studies with large telescopes can spectroscopically ascertain their nature. Table 5 shows the LG galaxies and references for their clusters and/or associations, if any. By columns: (1) and (2) Galactic coordinates, (3) and (4) J2000.0 equatorial coordinates α and δ, (5) and (6) large and small angular diameters, (7) designation(s), (8) type as normal or dwarf galaxy, (9) comments, (10) cluster and association contents and (11) reference code(s).

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