universe

Article

The Effect of Age on the Grouping of Open Clusters: The Primordial Group Hypothesis

Juan Casado

Facultad de Ciencias, Universidad Autónoma de Barcelona, 08193 Bellaterra, Barcelona, Spain; juan.casado@uab.cat

Abstract: The Primordial Group hypothesis states that only sufficiently young open clusters (OCs) can be multiple, and old OCs are essentially isolated. We tested this postulate through four different studies using a manual search of Gaia EDR3 and extensive literature. First, we revisited the work of de La Fuente Marcos and de La Fuente Marcos (2009), which states that only ca. 40% of OC pairs are of primordial origin. However, no plausible binary system among their proposed OC pairs having at least one member older than 0.1 Gyr was found. Second, we researched the OCs < 0.01 Gyr old in Tarricq et al. (2021) and found that ca. 71% of them remain in their primordial groups. Third, a similar study of the oldest OCs (age > 4 Gyr) showed that they are essentially alone. Forth, the well-known case of the double cluster in Perseus and some other binary systems described in the literature were also shown to accommodate the title hypothesis. A simplified bimodal model allows for retrieval of the overall fraction of related OCs (approximately 12–16%) from our results, assuming that young clusters remain associated at ~0.04 Gyr. The obtained results further support that OCs are born in groups (Casado 2021).

Keywords: open cluster pairs; open cluster groups; open cluster formation; Gaia; manual search; Primordial Group hypothesis

check for updates

Citation: Casado, J. The Effect of Age on the Grouping of Open Clusters: The Primordial Group Hypothesis. *Universe* **2022**, *8*, 113. https://doi.org/10.3390/universe8020113

Academic Editors: Laura Magrini, Germano Sacco, Lorenzo Spina and Mauro D'Onofrio

Received: 8 October 2021
Accepted: 3 February 2022
Published: 10 February 2022

1. Introduction

Open clusters (OCs) are born from the gravitational collapse of gas and dust in giant molecular clouds. There is observational evidence that some are born in groups [1,2]. Galactic OCs are sometimes found in pairs, and the number of these optical pairs is significantly higher than would be expected if clusters were randomly distributed (e.g., [3]). Studies of grouping among OCs provide keys to understanding star formation in the Galactic disk and the subsequent dynamical evolution of OCs.

Until recently, h and χ Persei was the only accepted physical double cluster in our Galaxy [4], even though some literature describing other OC pairs already existed (e.g., [5–7]). Conversely, roughly 10% of known OCs in the Large Magellanic Cloud (LMC) seem to belong to pairs [8]. Within the Galactic disk, the first estimations of the fraction of these paired clusters by statistical comparison of entirely random distributions of OCs or pairs of OCs reached a level of 20% [3]. Bica et al. [1] estimated that 25% of embedded clusters (EC) are formed in pair or triplet systems, although groups with up to nine OCs were also identified (see [9]). Subramaniam et al. [7] estimated that approximately 8% of the OCs in the Galaxy appear to be members of binary systems. De La Fuente Marcos [5] (DFM hereafter) argued that the real fraction was similar to that in the LMC. Among this population, nearly 40% of them were classified as primordial binary open clusters. However, only approximately 17% appear to survive for more than 25 Myr [10]. On the other hand, Soubiran et al. [11] used Gaia data sets and analyzed the 6D space phase volume. They recognized only five likely binary clusters and a group of five OCs differing by less than 100 pc in their Galactic position and 5 km/s in velocity from their high-quality sample of 406 OCs. Nevertheless, in a corrected version of the same work, Soubiran et al. [11] listed

21 candidate pairs. The exact fraction of related OCs in the Galaxy remains unknown at present. However, new precision Gaia data will hopefully ascertain it soon, at least for the solar neighborhood.

The second Gaia Data Release (Gaia DR2) provided precise astrometric data (position, parallax (*plx*), and proper motions (PMs)) and (1+2)-band photometry for approximately 1.3 billion stars [12] starting a new era in precision studies of Galactic OCs (among other subjects). The recent third release of Gaia early data results (Gaia EDR3; [13]) further improves the accuracy of the measurements for approximately 1.5 billion sources.

Today, virtually all new OCs are found through unsupervised algorithms that detect overdensities in high-dimensional space from the plethora of data in large stellar databases and information provided by space missions such as Gaia (e.g., [14,15]). The next step in validation and characterization is performed using automatic machine learning techniques. For instance, the approach applied by [15] detected hundreds of new OCs in the Gaia database. However, this method does not recover a fraction of the OCs from the literature, partly due to the non-existence of several of these OCs [16]. This fact suggests that their approach may also be unable to detect a fraction of undiscovered OCs [17]. Two recent studies identified dozens of previously unknown OCs via manual mining of the Gaia dataset [9,18]. These surveys were less productive in terms of quantity of new OCs and could not ensure completeness, either. However, they were more detailed, since the manual approach allows for going beyond a purely formal search of OCs. Each OC candidate is examined individually, based on extensive available data.

In one of these studies [9], a comprehensive list of 22 double or multiple OCs comprising 80 possible member clusters between the galactic longitudes of 240° and 270° was examined, with the help of Gaia EDR3 and the existing literature. We discovered that almost all the 52 most likely grouping members were OCs younger than 0.1 Gyr. We did not find any likely groups containing older OCs. These results suggest that most groups, if not all, are of primordial origin and are not stable for a long time, in line with similar conclusions obtained from study of the Magellanic Clouds [8,19]. Our results also suggest a low probability, if any, of pairs formed by tidal capture or resonant trapping, which would be due to the small likelihood of close encounters of OCs, and the even lower probability of tidal capture without disruption of at least one of the clusters. Estimations of the fraction of OCs that form part of groups (from 9.4 to 15%) support the hypothesis that the Galaxy and the Large Magellanic Cloud are similar in this respect, as well [5]. One of our conclusions was that OCs are generally born in groups, i.e., in clusters of clusters. The stellar formation process is depicted as more complex than previously thought. See, for instance, the complex structures derived in Vela-Puppis [20], and the case of Group C in this paper. Other studies suggest a similar scenario [21–23]. Groups of young OCs are the likely result of such a hierarchical and turbulent star formation process.

In the present work, we propose and test a hypothesis dubbed the Primordial Group hypothesis: i.e., only sufficiently young OCs can be multiple, and old OCs are essentially single, since the gravitational interaction between OCs in primordial groups is indeed weak, and the probability of gravitational capture of OCs originating in different molecular clouds is very low [8]. We tested this hypothesis via four distinct studies. In Section 3, we review some of the cluster pair candidates proposed by DFM. In Section 4, we look for companions of the clusters younger than 0.01 Gyr, and in Section 5, the same method is applied to OCs older than 4 Gyr. In Section 6, we revisit the case of the double cluster in Perseus and a few other binary cluster candidates from the literature, and Section 7 summarizes some concluding remarks.

In the present study, a pair (or group) of OCs refers to any candidate group of interacting OCs, whether gravitationally bound or not, while the term “binary cluster” is limited to gravitationally bound OC pairs.

2. Methodology

First, we conducted a more in-depth study of some of the proposed OC pairs in DFM, using data from the extensive literature and Gaia EDR3 (see Section 3). The main results are summarised in Table 1. The methods applied to find and select pairs of OCs have been detailed previously [9]. However, we recapitulate here the general methodology.

We started with a candidate member of a hypothetical pair (or group) of OCs. For each of these candidates, we looked for close correlations between coordinates, PMs, and parallax for all OCs within the studied area (at least 100 pc surrounding each studied OC). For example, if two OCs were close enough (i.e., at a projected distance of fewer than ten times the smaller of their radii and less than 100 pc), the rest of their astrometric data were compared. If there was any overlap in the data, considering uncertainty intervals of 3σ, both OCs were included in Table 2. The table was refined using the most accurate and recent parameters for individual OCs from reported studies using Gaia DR2 and Gaia EDR3, where possible. When the existing data were questionable, incomplete, or inconsistent between different authors, the OCs were manually re-examined using Gaia EDR3 to obtain the corresponding parameters. The Gaia EDR3 astrometric solution is accompanied by new quality indicators, such as the renormalised unit weight error (RUWE). RUWE allows sources with inaccurate data to be discarded [13]. We routinely discarded sources that had RUWE > 1.4. Unless otherwise stated, we also discarded sources of *Gmag* > 18 to limit parallax and PM errors, which increase exponentially beyond this magnitude threshold. The member stars of each new or re-examined OC were obtained through an iterative method detailed previously [18]. In summary, this method refines the approximate allowed ranges in position, PM and *plx*, initially obtained by eye, by examining the resulting CMD, which must include a maximum number of likely member stars but a negligible number of outliers (stars out of the OC' evolutionary sequences on its CMD). The error ranges in Tables 1 and 2 are not the standard uncertainties, but the absolute (maximum) errors that encompass all the member stars of each OC.

Following the criteria of previous studies, the obtained groups were refined by discarding OCs that were more than 100 pc away from any other member [9,11,24,25], assuming that all members are at the average distance (*d*) of the group. This cutoff was an order of magnitude and an unrestrictive maximum, as other studies have used more restrictive limits (e.g., DFM used 30 pc). Groups with differences in radial velocities (RV) >10 km/s were also discarded [9,24]. The other requirement for refining the groups was that $\Delta PM/plx$ (or $\Delta PM\ d$) be < 2 yr^{-1} between each pair of group members, using the units in Tables 1 and 2. The latter condition implies that the differences in tangential velocities are also less than 10 km/s. Some limiting cases for each group are discussed in the following sections.

A straightforward way to search for OC candidates linked to each studied OC was to plot a graph of the Gaia sources satisfying the examined OC constraints for the studied field. In this way, we could obtain plots similar to Figure 1, showing (or not showing) the associated OCs. These charts were free of most of the noise from unrelated field stars.

The data in the pre-Gaia literature are significantly less precise than those in Gaia, especially when considering PMs (generally excluded from the analysis) and ages [26]. Nevertheless, most of the reported data regarding *d*, RV, and even age of well-studied OCs have some value. Therefore, they are used in the individual discussion of candidate pairs to compare and confirm Gaia data or when no Gaia studies were found, as is the case for some of the reexamined OCs.

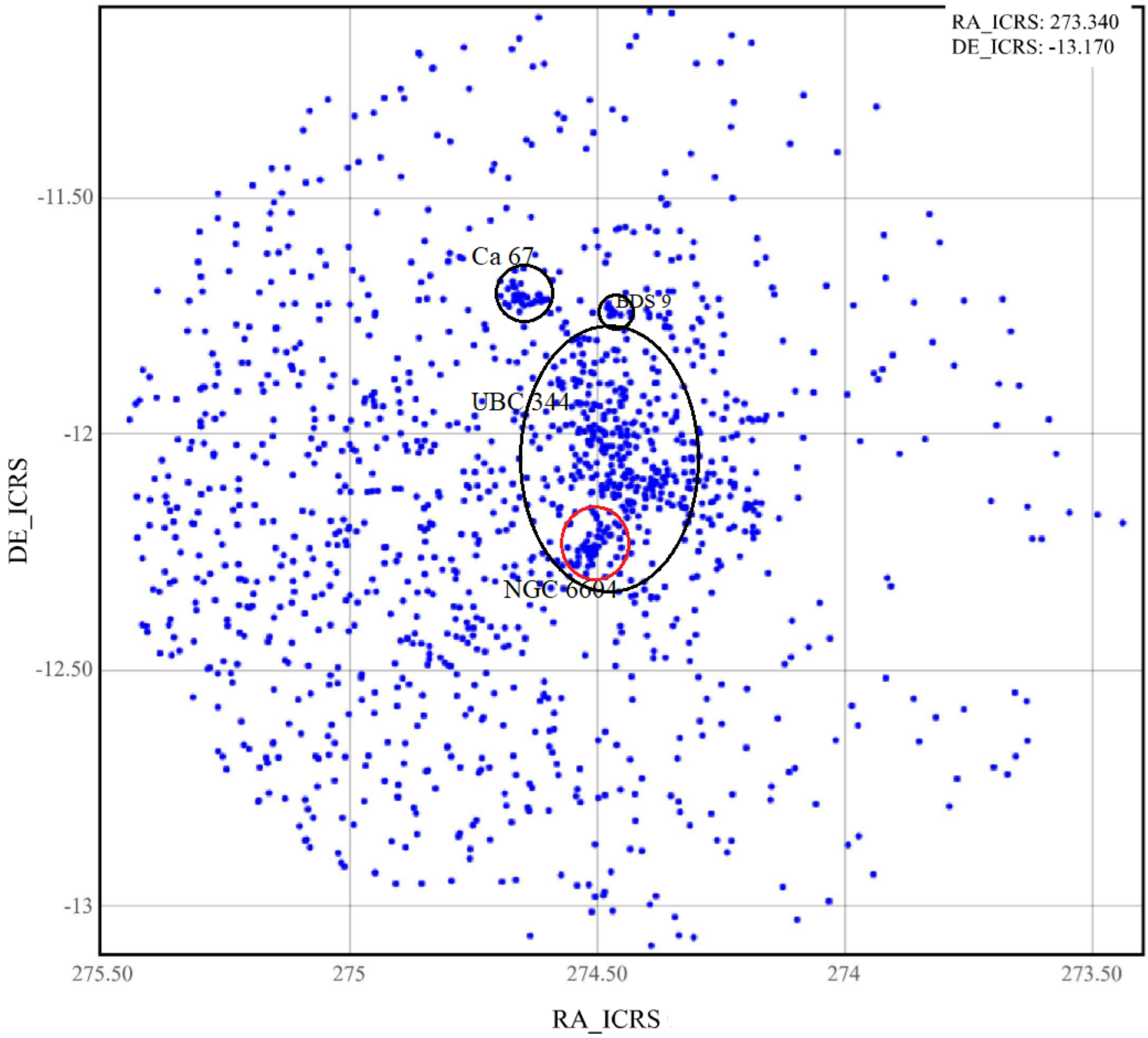

Figure 1. Chart of selected Gaia EDR3 sources defining group C. NGC 6604 is circled in red to differentiate it from the rest of UBC 344, outlined by a black ellipse. Constraints: *plx* 0.37 to 0.57 mas; μ_α −0.1 to −0.9 mas yr^{-1}; μ_δ −1.7 to −2.5 mas yr^{-1}; *Gmag* < 18.

3. Analysis of Candidate OC Pairs from DFM

DFM proposed numerous pairs of Galactic OCs and stated that only ~40% of cluster pairs are probably primordial. On the other hand, the statistics in Casado [9] suggest that the vast majority of candidate pairs and groups found are probably primordial. To test the Primordial Group hypothesis, in this section, we reexamined DFM's candidate pairs with at least one member older than 0.1 Gyr. If we found some binary systems that had at least one member > 0.1 Gyr, as suggested by DFM, the proposed hypothesis would be falsified.

The candidate pairs in DFM were only selected via their position and distance, which had to be compatible with a projected distance between them of less than 30 pc. We performed a deeper study using data from the extensive literature and Gaia EDR3. The main results are summarized in Table 1.

DFM considered OC data from two catalogs: the WEBDA Open Cluster Database [27] and the New Catalogue of Optically Visible Open Clusters and Candidates (NCOVOCC; [28]). In the following subsections, we discuss our findings with respect to each candidate pair comprising any member older than 0.1 Gyr.

3.1. WEBDA Catalog

Pair #1—ASCC100/ASCC101

DFM classified Pair #1 as a hyperbolic encounter, i.e., not a true binary system. Moreover, according to DFM, Pair #1 could be controversial: the member objects might not be real OCs. Although ASCC100 was not found through the algorithm of Cantat-Gaudin et al. [14], our manual study of ASCC 100 and the existing literature confirmed the existence of both OCs, although not their binary nature. Positions, parallaxes, and RVs are compatible, but PMs are disparate (Table 1). The difference in the mean parallaxes can be ascribed to a global offset of Gaia DR2 parallaxes, which are 0.029 mas too small on the whole [29]. Reported RVs for ASCC 100 range from −22.9 km/s [30] to −25.9 km/s [28], while for ASCC 101, RVs range from −15 km/s [31] to −32 km/s [24]. However, these similar RVs seem to merely reflect the general motion of stars in that particular region of the Galaxy. ASCC 100 is a relatively young OC, with all reported ages in the narrow interval from 0.089 Gyr [32] to 0.102 Gyr [33]. However, ASCC 101 is a mature OC, whose reported age ranges from 0.33 Gyr [33] to 0.49 Gyr [34]. Although not determinative, the different ages also suggest a chance encounter in the space of these otherwise unrelated OCs. The ensemble of results is consistent with the hyperbolic character of this pair. Note that, in hyperbolic encounters, the 3D positions should be close, but the 3D kinematics and ages should not.

Incidentally, Soubiran et al. [11] found ASCC101 as a possible binary with NGC 7058, but ASCC 101 and NGC 7058 are 185 pc apart according to these authors, making this pair highly unlikely. Moreover, the corrected version of this paper [11] does not include this pair in the final list of candidates.

Pair #5—ASCC 90/NGC6405

The Gaia DR2 mean parallaxes of ASCC 90 and NGC 6405 differ markedly, by approximately 27%, and the photometric distances are ~22% apart (Table 1). From the celestial coordinates and the distances (the more conservative approach), we inferred that both OCs are more than 100 pc apart, and the proximity condition would be not fulfilled. PMs in declination are only marginally compatible. The RV of ASCC 90 is in the interval 6.7 to 10.7 km/s, from seven member stars measured by Gaia DR2 [31]. However, NGC 6405 has at least six consistent RVs from −7.0 km/s [33] to −9.8 km/s [35]. Thus, the difference between mean RVs is ca. 17 km/s, significantly higher than the accepted threshold of 10 km/s. Unsurprisingly, their galactic orbital parameters do not fit. For instance, the eccentricity is more than one order of magnitude higher for ASCC 90 than for NGC 6405 [31]. All in all, the physical link of this candidate pair of OCs appears to be very doubtful.

Pair #7—Loden 1171/Loden 1194

Although there is a slight overdensity of stars near the position of Loden 1171, we were unable to find any evidence of this OC in Gaia EDR3. Moreover, the reported μ_α in the literature vary widely from -1.0 ± 3.7 [36] to -13.5 ± 0.3 [37]. There are also diverse reports regarding heliocentric distance, from 500 pc [38] to 789 pc [39], as well as angular diameter, from 9 arcmin [40] to 17.4 arcmin [39]. Neither parallax nor RV has been reported. Thus, it may well be a mere asterism, in which case pair #7 would be illusory.

Table 1. Selected possible open cluster groups (Gr) from DFM and candidate member properties revisited in this study (Section 3). Column headings: 1. Group number; 2. OC name; 3. Galactic longitude; 4. Galactic latitude; 5. Parallax; 6. Photometric distance; 7. PM in right ascension; 8. PM in declination; 9. OC radius; 10. Number of member stars; 11. Age; 12. Radial velocity. The suffix b in some of the groups refers to groups from the NCOVOCC catalog [28], as explained in the text. Abbreviations: [a] radius containing 50% of members; [e] reexamined using Gaia EDR3 due to insufficient, imprecise or inconsistent reports; [g] see text.

1	2	3	4	5	6	7	8	9	10	11	12	13
Gr	OC	l	b	plx	d	μ_α	μ_δ	R	N	Age	RV	References and Notes
	Name	degree	degree	mas	kpc	mas yr^{-1}	mas yr^{-1}	arcmin	stars	Gyr	km/s	
1	ASCC 101 [KPR2005]101	68.03	11.61	2.4_9	0.41	0.9_3	1.2_9	22.3 [a]	69	0.49–0.33 [g]	−15– −32 [g]	[34]
1	ASCC 100 [KPR2005]100	64.4	12.67	2.9 ± 0.4		2.2 ± 0.3	−3.1 ± 0.3	25	24	0.08_9- 0.10_2 [g]	$-22._9$– $-25._9$ [g]	This work [e]
5	ASCC 90 [KPR2005]90	354.22	−1.95	1.7_1	0.56	-1.6_3	-2.6_8	23.3 [a]	58	0.81- 0.65 [g]	8	[34] [31]
5	NGC 6405	356.58	−0.76	2.1_7	0.46	-1.3_1	-5.8_4	16.5 [a]	573	0.03_4	−9 [g]	[34]
8	ASCC 34 [KPR2005]34	209.67	7.02	-	0.48–0.55 [g]	−2.1	−0.4	12	22	0.34	-	[41]
8 9	Loden 46	282.56	2.25	0.88	1.1	−11.4	4.6	20 [a]	44	0.10– 1.0_7 [g]	24– 27 [g]	[14]
9	NGC 3228	280.76	4.49	2.0_4	0.50	−14.9	−0.7	$30._7$ [a]	117	0.03	−22 [g]	[34]
10	NGC 6469	6.56	1.97	0.59	1.7	0.6	0.8	3.7 [a]	48	0.07	$-7._3$	[34] [31]
10 12	Ruprecht 139	6.43	−0.18	0.29 ± 0.06	0.59	0.0 ± 0.2	−1.4 ±0.2	7	65	0.00_4– 1.1_2 [g]	68 ± 3	This work [e] [39]
12	Bochum 14	6.38	−0.50	0.32 ± 0.06	0.54–0.97 [g]	0.3 ± 0.3	−1.2 ±0.2	2	44	0.00_1–0.03_7	-	This work [e]
21	NGC 2447	240.05 240.04	0.15 0.15	0.97	1.0 1.0	−3.8 −3.6	3.9 5.1	12 [a]	731	0.58 0.58	22	[24] [34]
21	NGC 2448	240.76 240.85	−0.26 −0.43	0.88	1.0 1.1	−3.8 −3.4	4.7 2.9	16 [a]	121	0.02 0.10	24	[24] [34]
22	Biurakan 2	72.75	1.36	0.54	1.7	−3.2	−6.8	8.3 [a]	47	0.00_9	−20– −25 [g]	[34]
22	Ruprecht 172	73.11	1.01	0.26	3.6	−2.0	−3.7	2.5 [a]	82	1.0_5	14–15 [g]	[34]
23	NGC 6242	345.45	2.46	0.76	1.2_4 1.2_1	1.1	−0.8	6.2 [a]	471	0.07_8 0.08_3	2	[34] [31]
23	Trumpler 24	344.63	1.59	0.59		-0.2_7	−1.3		327	0.00_8	−35	[42]
27	Basel 8	203.85	−0.16	0.63	1.5	−0.1	−2.4	19 [a]	14	0.05– 0.13 [g]	11	[34] [24]
27	NGC 2251	203.61	0.11	0.66	1.5 1.5	0.7	−3.8	7.4 [a]	109	0.28 0.28	26	[34] [31]
33	Ruprecht 151	233.08	3.24	0.87	1.1_3 1.0_9	−4.3	3.2	6.8 [a]	41	0.45 0.49	26	[34] [31]
33	NGC 2428	233.09	2.70	0.71	1.3_2 1.2_9	−3.3	2.5	8.8 [a]	163	0.72 0.74	53	[34] [31]
9b	Loden 46	282.56	2.25	0.88	1.1	−11.4	4.6	20 [a]	44	0.10– 1.0_7 [g]	-	[14]
9b	ASCC 59 [KPR2005]59	283.83 283.82	−0.76 −0.52	0.30 ± 0.03 -	0.5_1	−5.1 ± 0.2 −4.8	3.6 ± 0.2 3.2	18 20	64 219	0.29	−4 -	This work [e] [41]
23b	Pismis 19	314.71	−0.31	0.26	3.5	−5.5	−3.2	2.1 [a]	430	0.63–1.1_2 [g]	$-29._6$	[34] [31]
23b	Trumpler 22	314.66	−0.59	0.39	2.4 2.4	−5.1	−2.7	6.2 [a]	140	0.02_4– 0.31 [g]	−38– −43 [g]	[34] [31]
26b	NGC 2421	236.28	0.06	0.34_3	2.6_8 2.5_8	−3.1	3.1	5.8 [a]	406	0.07– 0.09 [g]	89	[34] [31]
26b	Czernik 31	236.27	0.27	0.29_5	3.4 3.2	−1.9	3.0	2.3 [a]	71	0.02– 0.18 [g]	103	[34] [31]

Pair #8—ASCC 34/Loden 46

There is no evidence of ASCC 34 in Gaia EDR3, despite the presence of a small clump of stars resembling a cluster core near its alleged center (at galactic coordinates 209.679 + 7.030), which is only a chance alignment according to Gaia data. However, let us consider that ASCC 34 is a real OC, assuming that the existing literature is correct. From the data reported in DFM, the difference in μ_α between both OCs of this candidate pair would be 11.75 mas/yr. At DFM's assumed distance for this OC pair (540 pc), this would imply a differential tangential rate of more than 30 km/s, which would be too high for a binary system of OCs [24]. Moreover, the reported distances of ASCC 34 are 550 pc [38] and 477 pc [41]; therefore its average distance would be less than half the distance derived from Gaia data for Loden 46 (Table 1). Most importantly, the difference in galactic longitude of both objects (~73°) indicates that this pair was a selection error in DFM. For these given reasons, this candidate pair can be ruled out.

Pair #9—Loden 46/NGC 3228

Candidate pair #9 is formed by NGC 3228 and, again, by Loden 46, i.e., DFM considered a possible triple system. In this case, the existence of both OCs is undeniable, and their positions are close enough. The PMs are also (marginally) compatible. However, Loden

46's age is very poorly constrained, ranging from 0.10 Gyr [41] to 1.07 Gyr [38]. Since both estimations were produced by the same group of authors, we adopted the most recent determination as most accurate. However, in that case, Loden 46 would be a young OC, and thus this pair of OCs would be outside the scope of the present analysis. In any case, the reported RV for NGC 3228 (−22.4 km/s; [28,41]) is incompatible with the RV for Loden 46, which ranges from 24.3 km/s [31] to 26.7 km/s [43]. Their Gaia derived distances and parallaxes are also incongruent: NGC 3228 is much closer to the Sun than Loden 46, which rules out the actual existence of the alleged binary cluster and the triple system.

Pair #10—Ruprecht 39/NGC 6469

Again, most parameters of this candidate pair are disparate, including parallaxes, distances, μ_δ, ages and RVs (Table 1). The median reported heliocentric distance of Ruprecht 139, 0.59 kpc [39], close to the distance given in DFM (0.55 kpc), is congruent with neither the Gaia EDR3 parallax obtained in the present study nor the reported distance to NGC 6469. The presence of nebulosity around Ruprecht 139 is at odds with its older reported age (1.1 Gyr; [41]). Although this age is routinely quoted in the literature, the Kharchenko et al. [41] catalogue is not very suitable as a source of ages for young OCs. The reason is because the listed parameters (except PMs) were based on near-IR photometry (2MASS), and the corresponding CMDs have low age sensitivity in this age interval. A much younger age was obtained recently (0.004 Gyr; [25]). If Ruprecht 139 is a young OC after all, the inclusion of Pairs #10 and #12 in the present analysis would be pointless. Whatever the case, one of the plausible star members of Ruprecht 139 (Gaia EDR3 source 4069123828085540992) has RV = 68 km/s, which is incompatible with the reported RV of NGC 6469 (Table 1). All in all, the physical link of this pair is rather unlikely.

Incidentally, during study of this region using Gaia EDR3, three other OCs were identified that appear to be close to Ruprecht 139 and share compatible astrometric parameters, namely LP 1625, LP 1208, and LP 1209 [25], and could therefore be associated. However, the study of this possible group of OCs is outside the scope of the present report.

Pair #11—Johansson 1/Alesi 8

These OCs were recently identified, via Gaia DR2, with the associations of stars Theia 353 and 335, respectively [23]. Theia 353 is a string of stars of mean parallax 1.27 mas, while Theia 335 has parallax 1.48 mas. The difference between the parallaxes is at least 16%, and corresponds to a distance between both objects of more than 110 pc, which would exclude their present physical link. In addition, some of the astrometric parameters are not well-matched. For example, the Y positions in the heliocentric XYZ reference frame are −371 pc and −561 pc for Theia 335 and 353, respectively. Therefore, the existence of a binary cluster formed by these members is doubtful, despite both ages being very similar (and very close to the limit age for the present study): 102 and 106 Myr for Theia 335 and 353, respectively. However, the possibility that this pair could be a primordial one that has relaxed to the point that it does not meet the criteria that match younger open clusters cannot be excluded at present.

Pair #12—Bochum 14/Ruprecht 139

The physical link between Bochum 14 and Ruprecht 139 seems likely at first sight since they are apparently close, and their parameters are at least marginally compatible (Table 1). The reported distances to Bochum 14 vary from 0.54 kpc [39] to 0.97 kpc [44]. This range is compatible with the reported distance of Ruprecht 139 but contrasts with the Gaia EDR3 parallaxes of both OCs, which lead to derived distances of at least 3 kpc. Bochum 14 is a young cluster embedded in its parent molecular cloud, even if there is no consensus regarding its exact age, since reported values span from 1 Myr [45] to 39 Myr [25]. There is no consensus at all regarding the age of Ruprecht 139 (see pair #10). All in all, the gravitational capture of this pair is dubious, since the gravitational link of both OCs and the old age of Ruprecht 139 require confirmation. If Ruprecht 139 is young enough, this pair could be a primordial one.

Pair #13—Loden 565/ASCC 68

This alleged double cluster would be formed by Loden 565 and ASCC 68 (also known as [KPR2005] 68). A detailed study based on Gaia DR2 [46] concluded that Loden 565 is most likely a random stellar fluctuation. Thus, there is no case for any pair of OCs involving Loden 565. Incidentally, six out of sixteen OCs in the cited study were found to be mere stellar fluctuations, calling for a thorough review of assumed OCs in the pre-Gaia literature. Such work has recently been undertaken by refuting 38 "well-known" OCs [16].

Pair #14—VdBH91/Ruprecht 89

Perren et al. [46] also concluded that VdBH 91 is a random stellar fluctuation and not a real OC. Therefore, this candidate pair is a misconception, although the previously reported PMs and distances of both members seemed well-matched.

Pair #15—ASCC 4/NGC 189

This candidate pair is formed by ASCC 4 (or [KPR2005] 4) and NGC 189. The literature on ASCC 4 indicates that it should be detected in Gaia data since its reported distances range from 0.55 kpc [32,41] to 0.75 kpc [38]. However, we did not find any Gaia-based study that includes it, nor did we find any trace of its existence through manual mining of Gaia EDR3. In addition, the PMs from the literature are assorted, and the reported RV is comparable with its associated error [24]. Our preliminary conclusion is that this cluster of stars is a chance alignment. If confirmed, no group containing ASCC 4 could exist.

Pair #16—NGC 1746/NGC 1758

After reexamining NGC 1746 using Gaia DR2 data, Cantat-Gaudin and Anders [16] concluded that this alleged OC is a mere asterism. However, NGC 1750 is an apparently close OC that could be linked to NGC 1758. Moreover, at times all three objects have been considered one single object, catalogued as NGC 1746 (e.g., [41]). Thus, we have reconsidered the possibility of a pair of NGC 1750 and NGC 1758. Nevertheless, the reported RVs of -7.5 and 11 km/s, respectively [31], make their link unlikely. The rest of the astrometric Gaia measurements confirm the disparity of both OCs [34]. Hence, this candidate pair is, once more, not an actual binary system.

Pair #17—Basel 5/NGC 6425

Diverse distances, PMs and ages are reported for Basel 5, but the parallax and RV of this object are unknown. It is located in a very crowded field of the Milky Way. Our reexamination with Gaia EDR3 obtained no evidence of this OC (several halo stars probably related to NGC 6451 were recovered, instead). Similarly, Cantat-Gaudin and Anders [16] considered Basel 5 a mere asterism caused by extinction patterns. Therefore, any alleged pair containing it would not exist.

Pair #20—Ruprecht 91/ESO 128-16

This candidate pair was classified as a hyperbolic encounter by DFM because of their disparate kinematics. Therefore, it is not a linked system. Moreover, ESO 128-16 could be a spurious overdensity of stars, since we did not find any trace of it through manual mining of Gaia EDR3, although it was included in the catalog of Hao et al. [42] (see, however, comment on pair #16b).

Pair #21—NGC 2447/NGC 2448

DFM and Conrad et al. [24] proposed this binary OC. Despite some similar parameters, their different PMs suggest that both OCs may not be a physical system (Table 1). For instance, μ_δ are 5.1 and 2.9 mas/yr, respectively [34]. The combined Gaia data for PM and parallax led to a difference in tangential velocity up to 12 km/s, beyond the limit adopted for linked OCs. The difference between the parallaxes, higher than 10%, also seems to be significant. In fact, from the most recently reported Galactocentric coordinates [31], both OCs would be 114 pc apart, again exceeding the 100 pc permissive limit. Accordingly, their orbital parameters significantly differ. For example, the orbital pericenters are 9.781 ± 0.035 kpc and 9.145 ± 0.181 kpc [31]. Overall, pair #21 appears to be, at least, dubious.

There is no consensus regarding the age of NGC 2447. For instance, Liu and Pang [25] report 1.15 Gyr, while others obtain 0.58 Gyr [24,34]. In any case, this OC seems much older than NGC 2448 (Table 1).

Pair #22—Biurakan 2/Ruprecht 172

All reported RVs of Biurakan 2 range from −19.7 km/s [36] to −24.9 [47], with a consensus value of −22 km/s [24,33,35,41]. This RV is at odds with the reported RVs of Ruprecht 172: 14.1 km/s [31] and 15.4 km/s [11]. In addition, Gaia-derived parallaxes, distances, PMs and ages are incongruent for this candidate pair (Table 1). Although the disparity in ages is irrelevant in the present scrutiny, the mismatch of the rest of the parameters strongly indicates that these OCs form an optical pair since Ruprecht 172 is much farther away than Biurakan 2.

Pair #23—NGC 6242/Trumpler 24

This candidate pair was classified as a hyperbolic encounter by DFM, and their incongruent PMs and RVs support this view (Table 1). However, Gaia's mean parallaxes indicate that Trumpler 24 is much further away than NGC 6242. In any case, this pair cannot be a binary system.

On the other hand, Trumpler 24, a young and scattered embedded cluster, seems to be associated with NGC 6231 [48] and ESO 332-8 [43], two young OCs in the same star-forming complex.

Pair #25—ASCC 6/Stock 4

Although this candidate pair is included in the present review because, according to DFM, both OCs would be older than 100 Myr, the most recent reports disagree concerning their ages. For ASCC 6 ([KPR2005] 6), the two most recent determinations, based on Gaia data, agree upon an age of ca. 0.04 Gyr [34,49]. For Stock 4, the Gaia derived ages are ca. 0.07 Gyr [31,34]. Thus, this pair may well be a primordial system of very young OCs.

Pair #27—Basel 8/NGC 2251

The reported ages of Basel 8 span from 0.048 Gyr (e.g., [24]) to 0.13 Gyr [35]. Whatever the case, NGC 2251 seems to be older (Table 1), which motivates the inclusion of pair #27 in this review. Although the celestial positions and distances for Basel 8 and NGC 2251 are well-matched, their PMs are not (Table 1). From the PMs and parallaxes, a difference in tangential velocity of 12 km/s, higher than the agreed threshold, is obtained. The divergent RVs also cast doubt on the physical link of this pair of OCs.

Pair #31—Loden 165/Carraro 1

A reexamination of the star field of Loden 165 with the Gaia EDR3 catalogue did not show any trace of this OC, or at least no OC compatible with the literature data regarding Loden 165 (some star members of VdBH 99 and NGC 3293 were found instead). Accordingly, there is no consensus regarding the reported distances, PMs and ages of this star cluster. Moreover, there are no data concerning its parallax or RV. Thus, we suggest that Loden 165 is merely an asterism, and there is no pair of OCs including it.

Surprisingly enough, one of the reported distances and one of the reported ages of Loden 165 and its alleged companion Carraro 1 exactly coincide. Both OCs would be at 1900 pc from us, and their log (age in yr) would be 9.48 (3.02 Gyr). The source of these particular data in both cases was attributed to the WEBDA catalogue. This catalogue provides the bibliographic reference of the data for Loden 165 [50]. However, it does not include any data details or bibliographic sources corresponding to the listed age and distance of Carraro 1. Perhaps these coincident data may be due to a mistake encouraged by the close position of both objects, and these coincidences may have led to the erroneous assumption that both OCs form a double system.

Pair #33—Ruprecht 151/NGC 2428

The astrometric Gaia data for Ruprecht 151 and NGC 2428 do not coincide. Both parallaxes and photometric distances indicate that Ruprecht 151 is ca. 200 pc closer to us than NGC 2428 (Table 1). PMs and RVs confirm the mismatch. As a result, the orbital parameters are also significantly different [31]. Therefore, this is merely an optical pair.

3.2. NCOVOCC Catalog

The numbers of candidate pairs based on this catalogue data are denoted #1b, #2b, and so on to differentiate them from the candidate pairs from the WEBDA database.

Pairs #2b, #6b, #8b, #10b, #11b, #12b, #15b, #17b, #21b and #25b coincide with WEBDA pairs #1, #5, #9, #11, #15, #17, #21, #22, #27 and #31, respectively, which were previously discussed in Section 3.1.

Pair #9b—Loden 46/ASCC 59

We found, again, many disparities between both alleged members. The previously reported data regarding ASCC 59 were incomplete and somewhat inconsistent. Thus, we decided to reexamine it using Gaia EDR3 (Table 1). However, the new parallax is at odds with the previously reported distances for ASCC 59. Most importantly, the Gaia data regarding Loden 46 (see pairs #8 and #9) did not match any of the data for ASCC 59. Therefore, candidate pair #9b can also be surely discarded.

Pair #16b—ESO 132-14/NGC 5281

Despite the existence of a dense clump of a few stars at the center of ESO 132-14 that resembles an OC core, our manual inspection of Gaia EDR3 showed no trace of such an OC and revealed that the apparent core is a chance alignment of stars. However, Gaia should detect that cluster, since it was reported to be only 1.1 kpc away [28,32,44]. On the other hand, the catalogue of Hao et al. [42] reports a mean parallax of 0.39 mas, at odds with that distance for ESO 132-14. Parenthetically, this all-inclusive catalogue (3794 entries) encompasses numerous asterisms (e.g., NGC 1663, NGC 1746, Ruprecht 46, Ruprecht 155, Collinder 471, Basel 5, Loden 1 [16]) and duplicated OCs with different listed parameters (e.g., Alessi 44, Andrews-Lindsay 5, Arp-Madore 2, Havlen Moffat 1, VdBH 121), especially those in the ESO series (e.g., ESO 021-06, ESO 313-03, ESO 313-11, ESO 332-13, ESO 334-02, ESO 368-11, ESO 368-14, ESO 392-13, ESO 397-01, ESO 429-02). In addition, the previous literature regarding ESO 132-14 shows assorted PMs (e.g., [36,41]) and neither RV nor mean parallax measurements. Given all this conflicting evidence, we consider this OC and associated candidate pair unlikely to be physical.

Pair #23b—Pismis 19/Trumpler 22

The age of Trumpler 22 is poorly constrained. Pre-Gaia studies report ages up to 0.31 Gyr (e.g., [41]), but most recent works report ages close to 0.03 Gyr [31,34,49]. In any case, these values do not overlap with the reported ages of Pismis 19, a redder and older cluster with ages that range from 0.63 Gyr [51] to 1.12 Gyr [44]. Such an age disparity prompted the inclusion of this candidate pair in the present study.

Even if positions and PMs are compatible, distances and parallaxes are not. Pre-Gaia catalogs assigned Trumpler 22 photometric distances as low as 1.5 kpc (e.g., [28]). However, Gaia DR2-based studies agree on a photometric distance of 2.4 kpc (Table 1), which harmonizes with the measured parallax, allowing for the mentioned global offset of Gaia DR2 parallaxes [29]. In any case, all reported distances are significantly smaller than the distance (and corresponding parallax) of Pismis 19 (Table 1).

The reported RVs are not enlightening in this case. For Trumpler 22, RVs span from −38 km/s [28,35] to −43 km/s [11,31], which are only marginally compatible with the reported RV for Pismis 19 (Table 1). The ensemble of data suggests that this pair is a chance alignment, mainly because Trumpler 22 is more than one kpc closer to the Sun than Pismis 19.

On the other hand, the younger OC Trumpler 22 has been physically connected to NGC 5617 [52]. According to this study, the two close OCs share similar ages (~70 Myr), average RVs (−38.5 ± 2.0 km/s), and mean metallicities (−0.18 ± 0.02 dex), forming a primordial binary cluster.

Pair #26b—NGC 2421/Czernik 31

NGC 2421 is a well-known OC, but its age was poorly constrained before Gaia. However, four of the five Gaia-based studies converge on ages ranging from 0.066 Gyr [34] to 0.091 Gyr [31]. The age of Czernik 31 was also poorly constrained: reports range from 0.021 Gyr (e.g., [49]) to 0.18 Gyr [41]. The latter tentative age (see comment on pair #10), adopted in DFM, motivates the inclusion of this pair in the present work. Inspection of the data summarized in Table 1 suggests that this is an optical pair. Most of the parameters are incompatible. In particular, both the photometric distances and the mean Gaia parallaxes indicate that NGC 2421 is significantly closer than Czernik 31. The reported RVs and μ_α also do not match.

None of the revised candidate pairs was retrieved in the more recent and constraining study of Conrad et al. [24], except for the questionable case of NGC 2447 and NGC 2448. Moreover, Conrad et al. [24] warned that possibly many of the previously proposed groupings in the literature were not recovered in their survey because they are not real.

In sum, we did not find any likely binary clusters from the DFM study with any of their members older than 100 Myr. Some of the pairs are optical pairs, others are hyperbolic encounters, and a few pairs may be primordial pairs with flawed ages. A significant number of the clusters studied in this sample are most likely false OCs, namely Loden 1171, ASCC 34, Loden 565, VdBH 91, ASCC 4, NGC 1746, Basel 5, Loden 165, ESO 128-16 and ESO 132-14. The higher frequency of Loden objects suggests that that series of OCs might contain more flawed OCs than average. The preliminary conclusion of this section is that our working hypothesis has passed this trial and that most double or multiple OCs are primordial groups.

4. Groupings Surrounding Very Young OCs

The Primordial Group hypothesis suggests that very young OCs (age < 0.01 Gyr) may still be associated with their siblings, i.e., those clusters born recently from the same giant molecular cloud, although not necessarily so. We used the updated catalogue of Tarricq et al. [31] to investigate this possibility. This comprehensive catalogue lists well-studied OCs with both age and 3D kinematics. We studied the field of those OCs to look for associated siblings using the methodology described in Section 2.

SAI 25

Since there are inconsistent reports (even from Gaia data) concerning this faint, poorly populated OC, we contributed parameters based on Gaia EDR3 (Table 2). The reported distances range from 1.1 kpc [35] to 2.7 kpc [34]. Only the larger values are (marginally) compatible with Gaia parallaxes. Moreover, there is a very wide span of reported ages for SAI 25: from 0.002 Gyr [31,34] to 1.5 Gyr (e.g., [28,41,42]). Note that only if SAI 25 were indeed young would it be justified to include it in the present section. The broad and ill-defined CMD [34] has a short main sequence spanning only four magnitudes, suggesting that it is not so young. Whatever the actual age is, no associated OC was found in a radius of 100 pc surrounding SAI 25.

NGC 6823 (Group A)

NGC 6823 is so young that it is still associated with the HII region LBN 059.38-00.15. Reported ages range from 2 Myr [31] to 10 Myr [41]. It also seems to be associated with Roslund 2 (Table 2), whose reported ages range from 6 Myr [32,39,41] to 12 Myr [31]. Accordingly, most of the characteristics of both OCs are well-matched. Unfortunately, published RVs do not allow for confirmation of this possibility, mainly because of the wide disparity in Roslund 2's RVs, ranging from −5 km/s (e.g., [41]) to 127 km/s [11,31]. Notice, however, that RVs of NGC 6823 range from 11 km/s to 30 km/s, so that both intervals are compatible. All in all, this pair is considered a likely double cluster candidate.

Hogg 15 (Group B)

Hogg 15 is perhaps associated with the EC La Serena 39 [40]. We reexamined this last cluster with Gaia EDR3, but the results were insufficient for a complete characterization due to the few star members and the high number of associated errors (Table 2). RV and age are unknown, but since it is an EC, it should be very young. In the case of Hogg 15, the reported ages range from 2 Myr [31,34] to 20 Myr [44]. In any case, only the astrometric and PM data are compatible. All in all, this candidate pair is considered dubious.

The small OC [MCM2005b]32, which was also classified as an EC [40] and is associated with a mid-IR extended emission [53], may belong to the same group. We studied it using Gaia EDR3 since very few data regarding this cluster have been reported (Table 2). The RV from the associated gas line velocity is barely compatible with the RV of Hogg 15 (Table 2). Although the distance between this cluster and Hogg 15 appears to be 0.13 kpc, the Gaia EDR3 results are well-matched with those of Hogg 15. Its membership is therefore uncertain. It is noteworthy at this point that if two clusters born together are in the process of separation, sooner or later, they will go beyond the 0.1 kpc limit, which is therefore arbitrary [9]. In other words, the separation of sibling OCs may well increase with time as the systems become more and more dynamically relaxed.

Lynga 6

No close OC to Lynga 6 was found when considering both its 3D position and 3D kinematics.

Table 2. Selected possible open cluster groups (Gr) and candidate member properties studied in this work (Sections 4 and 5). Column headings: 1. Group label; 2. OC name; 3. Galactic longitude; 4. Galactic latitude; 5. Parallax; 6. Photometric distance; 7. PM in right ascension; 8. PM in declination; 9. OC radius; 10. Number of member stars; 11. Age; 12. Radial velocity. Abbreviations: [a] radius containing 50% of members; [c] maximum cluster member's distance to average position; [e] reexamined using Gaia EDR3 due to insufficient, imprecise or inconsistent reports; [f] too few stars for complete characterization; [g] see text; [p] protocluster or embedded cluster; (?) unlikely group.

1	2	3	4	5	6	7	8	9	10	11	12	13
Gr	**OC**	*l*	*b*	*plx*	*d*	μ_α	μ_δ	*R*	*N*	*Age*	**RV**	**References and Notes**
	Name	**degree**	**degree**	**mas**	**kpc**	**mas yr^{-1}**	**mas yr^{-1}**	**arcmin**	**stars**	**Gyr**	**km/s**	
-	SAI 25	139.70	−1.33	0.30 ± 0.11	1.1–2.7 [g]	0.2 ± 0.2	$-0.7_5 \pm 0.3$	2.5 ± 0.5	19 [f]	1.5–0.00_2 [g]	- −66	This work [e] [31]
A	NGC 6823	59.42	−0.14	0.45	2.3 2.2	−1.7	−5.3	4.4 [a]	140	0.00_2–0.01_0 [g]	11–30 [g]	[34] [31]
A	Roslund 2	60.21	−0.18	0.46	2.1 2.0	−1.7	−5.1	9.6 [a]	97	0.00_6–0.01_2 [g]	127	[34] [31]
B	Hogg 15	302.05	−0.24	0.27	3.0 2.9	−6.0	−0.5	3.8 [a]	72	0.02_0–0.00_2 [g]	−23	Cantat-Gaudin+ 2020 [31]
B	La Serena 39	301.10	−0.17	0.30 ± 0.08		−5.9 ± 0.3	−0.4 ± 0.2	3.0 ± 0.5	16 [f]		-	This work [e]
B	[MCM2005b]32	300.13_5	-0.08_5	0.26 ± 0.07		−6.1 ± 0.2	−0.3 ± 0.2	1.0 ± 0.5	15 [f]		- −39	This work [e] [44]
C	UBC 344	18.35	1.82	0.47	1.9_2 1.8_4	−0.3	−2.2	9.7 [a]	314	0.00_3 0.00_3	42	[34] [31]
C	NGC 6604	18.24	1.69	0.45	1.8_9	-0.4_5	−2.3	1.0–17 [g]	88	0.00_3-0.00_8 [g]	−5–136 [g]	[43]
C	[BDS2003]9	18.67	1.97	0.49 ± 0.10		−0.5 ± 0.3	−2.0 ±0.3	1.5 ± 0.5	16 [f]		-	This work [e,p]
C	Casado 67	18.78	1.83	0.47 ± 0.08	2.2	$-0.4_5 \pm 0.2$	$-2.0_5 \pm 0.3$	2.5 ± 0.5	27	0.01	-	This work [p]
D	NGC 6383	355.67	0.06	0.87	1.1_2 1.0_9	2.6	−1.7	4.9 [a]	245	0.00_4 0.00_4	2	[34] [31]
D	Casado 68	354.54	0.20	0.87 ± 0.10	1.2	$2.5_5 \pm 0.4$	−1.8 ± 0.4	13 ± 1	52	0.01	4	This work [p]
E	NGC 1893	173.58	−1.63	0.27	3.2_2 3.1_5	−0.2	−1.4	5.1 [a]	123	0.00_4 0.00_4	−4	[34] [31]
E	Casado 69	173.16	−1.30	0.30 ± 0.09		−0.3 ± 0.3	−1.6 ± 0.4	3.5 ± 0.5	17 [f]		-	This work [p]
F	NGC 6193	336.69	−1.58	0.81	1.2_6 1.2_3	1.3	−4.1	9.4 [a]	428	0.00_5 0.00_5	−76	[34] [31]
F	Casado 70	336.35	−1.20	0.84 ± 0.09	1.1	1.3 ± 0.5	−4.3 ± 0.4	7 ± 1	63	0.01	-	This work [p]
G	NGC 3572	290.74	0.17	0.38	2.4_6 2.3_5	−6.3	1.9	4.4 [a]	75	0.00_5 0.00_5	1	[34] [31]
G	Hogg 10	290.78	0.15	0.37	1.8–2.5 [g]	−6.2	1.9	1–8	44	0.00_6	1–−7 [g]	[42]
G	LP 1531	291.02	0.04_4	0.38_5		−6.2	1.8	6.7 [c]	57	0.00_4	-	[25]
H	FSR 0198	72.18	2.61	0.49	2.1_8 2.0_4	−3.6	−6.6	7.6 [a]	82	0.00_5 0.00_5	12	[34] [31]

Table 2. *Cont.*

1	2	3	4	5	6	7	8	9	10	11	12	13
Gr	**OC**	*l*	*b*	*plx*	*d*	μ_α	μ_δ	*R*	*N*	*Age*	**RV**	**References and Notes**
	Name	**degree**	**degree**	**mas**	**kpc**	**mas yr^{-1}**	**mas yr^{-1}**	**arcmin**	**stars**	**Gyr**	**km/s**	
H	Teutsch 8	71.86	2.42	0.49	1.9_8	−3.5	−6.7	0.4 [a]	28	0.00_4	-	[34]
I	NGC 2362	238.18	−5.55	0.74	1.3_4 1.3_0	−2.8	3.0	3.1 [a]	144	0.00_6 0.00_6	29	[34] [31]
I	Camargo 997	237.50	−4.89	0.80 ± 0.13		−2.8 ± 0.3	3.0 ± 0.3	8.5 ± 0.5	49		30	This work [e,p]
J	UBC 438	195.70	0.03	0.21	3.6 3.3	0.2	−0.4	5.8 [a]	24	0.00_4 0.00_6	39	[34] [31]
J	Casado 71	195.29	0.45	0.21 ± 0.06		0.3 ± 0.2	−0.5 ± 0.2	3.0 ± 0.5	14 [f]		-	This work
H_1	NGC 6871	72.66	2.01	0.51	1.7_2 1.6_6	-3.1_3	-6.4_4	22 [a]	430	0.00_5 0.00_6	15	[34] [31]
H_1	Teutsch 8	71.86	2.42	0.49	1.9_8	-3.4_9	-6.7_0	0.4 [a]	28	0.00_4	-	[34]
K	IC 1805	134.73	0.94_5	0.45	1.9_6 1.8_7	−0.7	-0.6_7	6.7 [a]	106	0.00_8 0.00_7	−44	[34] [31]
K	Berkeley 65	135.84	0.26	0.44	2.2_8	−0.7	-0.3_4	1.5 [a]	37	0.09_7	-	[34]
K	Camargo 755	134.81	1.32	0.45 ± 0.11		−0.7 ± 0.3	−0.3 ± 0.2	5 ± 1	44		-	This work [e,p]
L	VdBH 205	344.63	1.63	0.57	1.6_0 1.5_4	−0.2	−1.1	5.8 [a]	55	0.00_6 0.00_7	−2	[34] [31]
L	ESO 332−08	344.39	1.79	0.53	1.6_9	−0.3	−1.3		201	0.00_8	-	[43]
L	[DBS2003]114	345.32	1.46	0.56 ± 0.10		−0.2 ± 0.4	−1.4 ± 0.3	1.5 ± 0.5	19 [f]		-	This work [e,p]
M (?)	Berkeley 36	227.50	−0.56	0.20_6	4.3_6 4.1_3	-1.7_3	0.8_6	2.8 [a]	150	6.8 6.8	63	[34] [31]
M (?)	Casado 72	227.25	−0.82	0.26 ± 0.06	3.8	$-1.5_5 \pm 0.2$	$0.8_5 \pm 0.2$	5 ± 0.5	19	0.02	-	This work
N (?)	Kronberger 81	95.27	2.07	0.23	- 4.1	-2.6_1	-3.3_2	2.7 [a]	28 [f]	- 5.6	−85	[34] [31]
N (?)	Teutsch 17	95.31	1.06	0.25_3 0.26_7	2.9	-2.8_8 -2.8_8	-3.2_1 -3.2_2	$11._6$ [c]	213 58	0.01_2– 0.08_3	-	[43] [25]
-	NGC 2383	235.27	−2.46	0.28	3.5	−1.6	1.9	2.2 [a]	242	0.26	55–72 [g]	[34]
O	NGC 2384	235.39	−2.39	0.38 ± 0.09	2.0–3.2 [g]	−2.3 ± 0.3	3.1 ± 0.3	4.0 ± 0.5	36	0.00_6–0.02_1 [g]	46–53 [g]	This work [e]
O	Casado 73	234.69	−2.19	0.33 ± 0.06	3.1	−2.2 ± 0.2	3.1 ± 0.3	3.5 ± 0.5	23	0.08	-	This work

UBC 344 (Group C)

According to data from Cantat-Gaudin et al. [34], UBC 344 is a big (up to 40 arcmin) and elongated cluster (Figure 1), containing a few cores in a nebular area. From the plot of its member stars, it became clear that one of the cores corresponds to NGC 6604, but it is unclear if NGC 6604 is part of UBC 344 or if they are two associated OCs. Note, however, that some of the UBC clusters recently discovered by [15] were already known OCs [54]. The apparent diameter reported for NGC 6604 in the pre-Gaia literature ranges from 2.0 arcmin [45] to 9.0 arcmin [40]. However, Liu and Pang [25] estimated the diameter to be 34 arcmin from Gaia DR2, similar to the size of UBC 344. The centers of both objects are ca. 10 arcmin apart. Most reported ages of NGC 6604 range from 3 Myr [55] to 8 Myr [41], and there is a broad consensus at approximately 6 Myr (e.g., [28,33,43,56–58]. Therefore, both clusters are very young (Table 2). The rest of the relevant parameters are also well-matched (Table 2), except for the RV of NGC 6604, which is very poorly constrained: from −5 km/s [28] to 136 km/s [42]. All in all, there is likely a relationship between both objects. The general appearance resembles a rich OC in the process of disintegration (Figure 1).

Two additional OCs were identified as possible members of Group C: [BDS 2003] 9, a cluster still embedded in the parent nebula Gum 85, and the new OC Casado 67, found in this survey (Figure 1 and Table 2). This last object, embedded in the same giant molecular cloud, is in an area containing numerous young stellar object candidates, which suggests that it is also very young. Accordingly, its estimated age determined from isochrone fitting (Figure 2) is 0.01 Gyr, compatible with the ages of other members of Group C. The derived photometric distance is 2.2 kpc, in good agreement with the mean Gaia EDR3 parallax. The estimated extinction of this new OC is A_V = 4.5 mag. A small clump of ca. ten stars at galactic coordinates 18.18, 2.02 also seems to belong to the same star-forming complex.

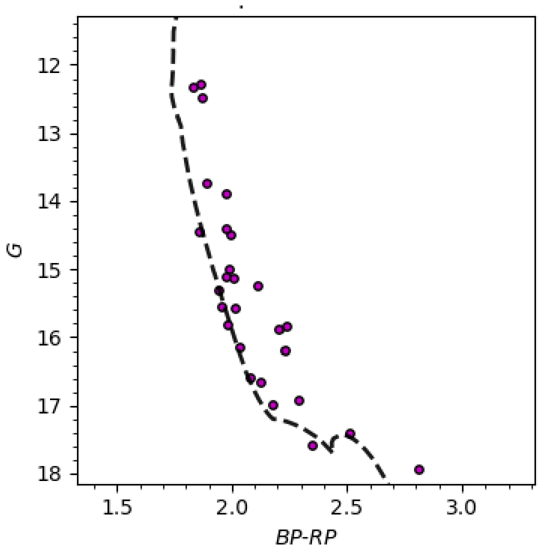

Figure 2. CMD of the most likely members of the new OC Casado 67 and the best fitting isochrone. Constraints are defined in Table 2.

NGC 6383 (Group D)

This candidate pair, formed by NGC 6383 and a newly identified sparse OC (Casado 68), appears associated with a giant molecular cloud that presumably is the nest where both were born not many Myr ago (Table 2).

NGC 6383 is a well-studied OC, which presents some substructure at its galactic north, suggesting partial disaggregation. Its reported RVs range from −1.2 km/s [24] to 7.7 [59], constituting the mean value in Table 2. The cited RV range fits the RVs of two of the member stars of Casado 68 (Gaia EDR3 sources 4054489126483224704 and 4054444287024098048), which are 4.2 km/s and 4.6 km/s, respectively. The photometric distance of Casado 68 is 1.2 kpc (Figure 3), compatible with the distance of NGC 6383 and with the mean parallaxes of both OCs. The extinction of the new OC is A_V = 1.1 mag. The rest of their parameters in Table 2 are also well-matched. This agreement suggests the membership of both OCs in the same primordial group.

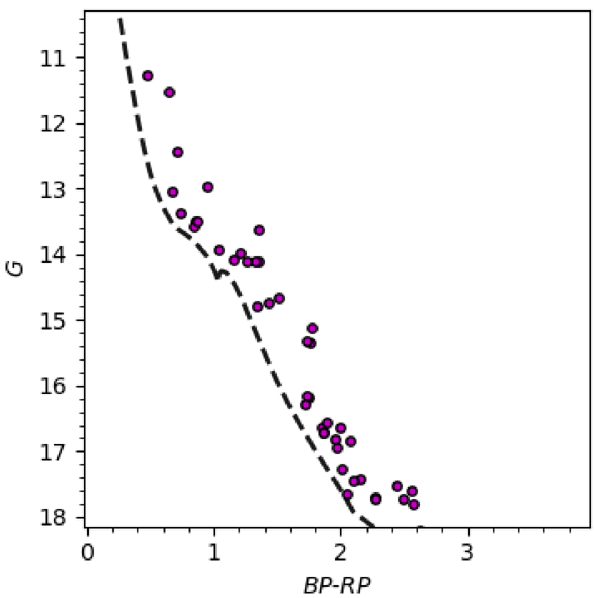

Figure 3. CMD of the most likely members of the new OC Casado 68 and the best fitting isochrone. Constraints are defined in Table 2.

FSR 0826

No OC linked to FSR 0826 was found when considering both its 3D position and 3D kinematics.

NGC 1893 (Group E)

NGC 1893, still embedded in its parent molecular cloud, might be associated with the as yet unknown OC Casado 69. This new cluster is still embedded in HII region IRAS 05197 + 3355, suggesting it is also young. The 6D astrometric parameters of both OC are well-matched, except for the RV, which is unknown for the star members of Casado 69. However, a reported RV of −4.4 km/s for IRAS 05197 + 3355 [60] fits perfectly with the mean RV for NGC 1893 (Table 2), which supports the case for a genuine pair. In this regard, all reported RVs of NGC 1893 range from −2.2 km/s [24] to −9.2 km/s [41].

NGC 6193 (Group F)

NGC 6193 could be associated with the new OC Casado 70, apparently embedded in the same molecular cloud and partially covered by the dark nebula DOBASHI 6513. As shown in Table 2, all astrometric parameters match well, except for the RV, which is unknown for the likely stellar members of Casado 70. The photometric distance of the new OC is compatible with its mean parallax and with the distance to NGC 6193. The estimated extinction of Casado 70 is A_V = 1.4 mag. Both OCs appear to be young and have a common origin, as their combined CMD fits quite well considering the presence of associated nebulosity (Figure 4). Moreover, estimation of the age of Casado 70 via isochrone fitting confirms that preliminary assumption (Table 2).

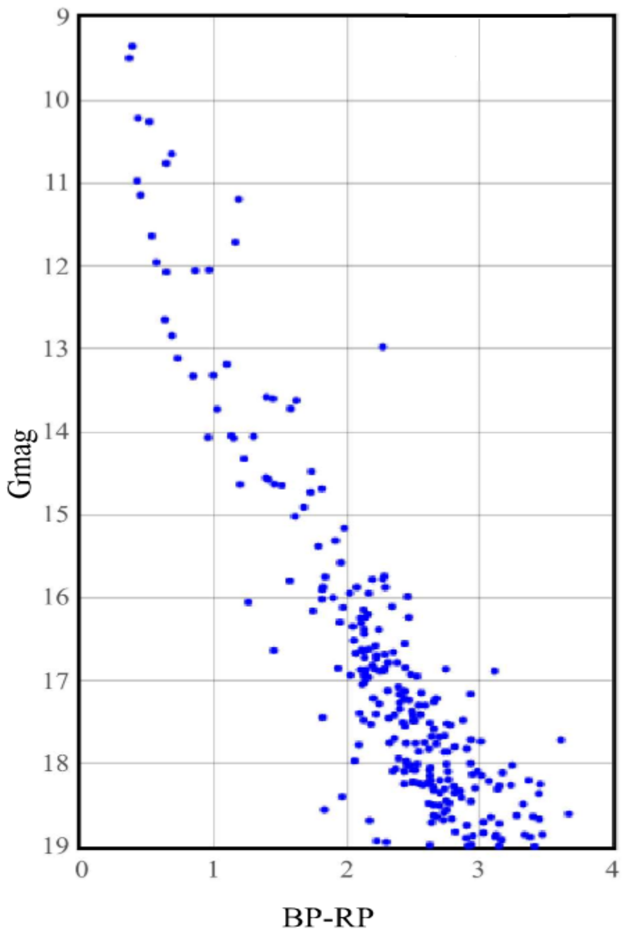

Figure 4. Combined CMD plot of the candidate primordial pair formed by NGC 6193 and Casado 70. Constraints: *plx* 0.77 to 0.95 mas; μ_α 0.7 to 1.8 mas yr^{-1}; μ_δ −4.0 to −4.8 mas yr^{-1}; *Gmag* < 19; *r* = 22 arcmin, centered at galactic coordinates 336.51, −1.39.

NGC 3572 (Group G)

This OC, adjacent to the parent molecular cloud [RC2004] G290.6 + 0.2–18.1, seems associated with the close OC Hogg 10. Moreover, some of the stars in Hogg 10 could belong to NGC 3572, according to data in Cantat-Gaudin et al. [34]. As summarized in Table 2, all Gaia derived parameters are consistent for both OCs. Reported distances to Hogg 10 range from 1.8 kpc [35] to 2.5 kpc [61]. This range encompasses the distance of NGC 3572 (Table 2). RVs of −7 km/s [41] and 1 km/s [28] were reported for Hogg 10, which are also compatible with that of NGC 3572 (Table 2). Last but not least, most reported ages are close to 6 Myr [28,35,41,42,56,62], i.e., close to the age of NGC 3572. Thus, this pair fulfills all requirements of a primordial system.

Another candidate group member is the recently discovered cluster LP 1531 [25], which we confirmed as a genuine OC using Gaia EDR3. All relevant parameters in Table 2 are well-matched with the other Group G members, although we did not find any member star of LP 1531 with a measured RV.

FSR 0198 (Group H)

This OC appears to form a double system with Teutsch 8. All relevant parameters are well-matched within the observational error (Table 2). However, no RV was retrieved for Teutsch 8. This group could involve a third member: NGC 6871 (see below).

Pismis 27

Pismis 27 might be associated with the possible EC [KPS2012] MWSC 0759 [41], but such a relationship is uncertain, as is the definitive classification of [KPS2012] MWSC 0759.

UBC 568

No evidence of an OC associated with UBC 568 was found when considering position, parallax and PMs.

NGC 7067

This NGC cluster has a second core of ca. ten stars at galactic coordinates 91.24, −1.72, which could either be a result of the fragmentation of a primordial OC or the outcome of a second OC born from the same parent molecular cloud. The apparent distance between both centers is ca. 5 arcmin, which corresponds to a projected distance of at least 10 pc, considering the mean parallax of NGC 7067 (0.15 mas; [34]). This mean parallax is used since the reported distances are very different. No other associated candidates were found within a radius of 100 pc, considering all the astrometric Gaia data.

NGC 2362 (Group I)

NGC 2362 seems to be associated with the EC Camargo 997, which is characterized here for the first time using Gaia EDR3. The mean parallax of Camargo 997 is less precise than usual due to the interference of nebulosity. However, all astrometric parameters are well-matched within the observational error (Table 2). Camargo 997 appears to still be partially embedded in the reflection nebulae Ced 96a and [RK68] 70, suggesting it is also a very young cluster. Both CMDs are well-matched. A conceivable star member of this cluster (Gaia EDR3 5617723283645039616) has an RV of 30 km/s, although it is 13 arcmin apart from its apparent center. This RV can be accommodated within the reported RVs of NGC 2362: from 25 km/s [33] to 36 km/s [28]. The data ensemble suggests that both clusters probably form a primordial system.

UBC 438 (Group J)

UBC 438, an elongated OC recently discovered by Cantat-Gaudin et al. [34], seems to be associated with the new OC Casado 71. All known astrometric data are compatible (Table 2). Although some of the reported distances for UBC 438 may seem small considering the reported mean parallaxes, an updated estimation of 4.1 kpc [43] alleviates this minor discrepancy, possibly due to the high relative error of parallax. From the data ensemble, the link between both OCs looks plausible, but the actual existence of Group J requires confirmation.

NGC 6871 (Group H_1)

This Group could be related to Group H (see below). NGC 6871 is a large, rich OC with some substructure and at least two cores. Liu and Pang [25] proposed NGC 6871 and Gulliver 17 as candidate members of an OC group. However, most Gaia astrometric parameters of both OCs, particularly the PMs, are discordant. On the other hand, NGC 6871 might be associated with Teutsch 8, even though distances and PMs are not identical (Table 2). For NGC 6871, the reported photometric distances range from 1.51 kpc [61] to 1.84 kpc [14], while for Teutsch 8, distances reported in the literature span from 1.60 kpc [28] to 1.98 kpc [34]. Given their similar parallaxes, both OCs are likely to be at a compatible distance according to the ensemble of data (~1.9 kpc). There is a consensus regarding the mean PMs derived from Gaia data, which seem coherent for both OCs. Quantitatively, ΔPM/*plx* (and ΔPM *d*) are ~0.9, which implies an acceptable difference in tangential velocities (<5 km/s).

If NGC 6871 were related to Teutsch 8, it would also be associated with FSR 0198 (see Group H). The similar RVs of NGC 6871 and FSR 0198 from Gaia DR2 (Table 2) increase the likelihood of a triple Group. However, there is no consensus in the literature regarding the RV of NGC 6871. The ages of the three candidate members are again compatible with a unique (and recent) origin. Altogether, the case for a triple primordial group seems likely.

IC 1805 (Group K)

Astrometric Gaia data strongly suggest that IC 1805, a cluster embedded in its parent molecular cloud, is associated with Berkeley 65, even if a slight difference in μ_δ is observed in Table 2. However, the photometric distances seem different at first sight. Nonetheless, most reported values of Berkeley 95 range from 1.9 kpc [63] to 2.28 kpc [34], while for IC 1805, photometric distances range from 1.7 kpc [41] to 2.34 kpc [28]. Thus, considering the consistent Gaia parallaxes, both clusters could be at a distance of ~2.1 kpc. The ages of both OCs seem somewhat different (Table 2), but there is no consensus regarding the age of Berkeley 65: This OC could be only 6 Myr old [25,62,64].

The candidate cluster Camargo 755, partially embedded in nebula BRC 7, might also be a component of the same group. We studied the field with Gaia EDR3 and confirmed the existence of a physical cluster, whose astrometric mean parameters almost perfectly fit with those of Berkeley 65 (Table 2). The fact that Camargo 755 is an EC suggests that it is also very young. It is, therefore, a good candidate member for Group K. The EC MDF 10 [40], in giant HII region IC 1795, might be another member of the group, but this possibility requires confirmation.

VdBH 205 (Group L)

The parameters of VdBH 205 are similar to those of ESO 332-08 (Table 2), which suggests that both clusters were born recently from the same molecular cloud where they are still embedded. The parallax of ESO 332-08 seems somewhat smaller, but a new value of 0.59 mas [42], based on Gaia EDR3, seems to solve this discrepancy and is roughly consistent with a global distance of ~1.7 kpc. Congruently, most reported values for VdBH 205 range from 1.54 kpc [31] to 2.16 kpc [28]. The ages of both clusters are also similar. Thus, although no RV was retrieved for ESO 332-08, our preliminary conclusion is that both objects are probable members of Group L. Unexpectedly, the OC UBC 323 [34] seems to encompass some member stars of both OCs.

The Infrared star cluster [DBS2003] 114 [44], likewise embedded in the HII region [CH87] 345.308 + 1.471, is also a firm candidate to be a member of the same group. The reported gas line velocity (−15 km/s) seems at odds with the RV of VdBH 205 in Table 2, but a compatible RV of −7 km/s was frequently reported [24,28,41].The additional parameters retrieved using Gaia EDR3 are well-matched with their siblings (Table 2).

UBC 19

No linked OC was found in a field 20 degrees wide surrounding this nearby cluster.

In sum, we found that 12 out of 20 studied young OCs (<0.01 Gyr old) have at least one primordial companion. Three candidate Groups are dubious, and no companion was found for five of the young clusters. Therefore, the total number of Groups ranges between 12 and 15 out of a total sample of 19 young OCs (SAI 25 was not taken into account as it is not likely to be young). The resulting statistic suggests that the probability of the sample of young OCs having linked siblings is 71 ± 8%. This ratio amounts to ca. six times the average fraction of linked clusters versus the total OC population in the Galaxy and the Magellanic Clouds, which is estimated at approximately 12% ([9] and references therein).

5. Groupings Surrounding Old OCs

Conversely, 18 out of the 20 oldest OCs listed in Tarricq et al. [31] prove to be single OCs. All of them are believed to be older than 4 Gyr. These are Berkeley 17, NGC 188, NGC 6791, Collinder 261, NGC 1193, Berkeley 39, Trumpler 19, Berkeley 32 (an apparent link to Czernik 27 has been discarded), Berkeley 20, FSR 1521, Melotte 66, FSR 1407, NGC 2243, Haffner 5, Trumpler 5, ESO 092-05, King 11, and Berkeley 18. There are, however, two possible exceptions to this general rule:

Berkeley 36 (Group M)

Berkeley 36 might be associated with the new OC Casado 72. However, this affiliation requires confirmation since both parallaxes are only marginally compatible, even correcting for the general offset of Gaia DR2 parallaxes [29]. The parallaxes, if correct, would imply that Berkeley 36 is ca. 400 pc farther away than Casado 72, and both OCs would form merely an optical pair. The estimation of the photometric distance of the new OC, consistent with its mean parallax, endorses that assumption (Table 2). On the other hand, the difference in mean PMs between both objects (0.18 mas/yr) would correspond, at an assumed distance of 4 kpc, to a difference of 3.4 km/s in tangential velocity. Unfortunately, there is no known RV for the new OC. The CMDs of both OCs do not match, and accordingly, their ages are completely different (Table 2). Thus, Group M, if confirmed, would not be primordial. Nevertheless, from the ensemble of results, the physical existence of this double cluster appears very doubtful at present. The interstellar extinction of Casado 72 is A_V = 1.6 mag.

Kronberger 81 (Group N)

Kronberger 81 may form a double system with Teutsch 17. The ensemble of astrometric results seems to fit reasonably well. However, the photometric distances and ages are not alike. There is no consensus regarding the distance of Kronberger 81. Values span from 2.5 kpc [35] to 7.6 kpc [63]. However, the mean value in Table 2 seems to be a reasonable compromise, since it also agrees with the reported parallax. The photometric distance of Teutsch 17 (Table 2) appears to be too small for the corresponding parallax, but no other distance was retrieved. If both OCs were roughly at the same distance from the Sun, such as ~4 kpc, the distance between them would be >70 pc. The reported ages of Teutsch 17 (Table 2) are discordant, but both values are much lower than the age of Kronberger 81. Nonetheless, Kronberger 81 could also be 0.4 Gyr old [28,41]. Unfortunately, no RV has been retrieved for Teutsch 17. All in all, the physical link of this candidate pair is uncertain.

Considering all these cases, the probability of any old cluster being part of a binary system appears to be <10% and, most likely, is close to 0.

The theoretical models indicate that binary cluster lifetimes range from a few Myr to ca. 0.04 Gyr (e.g., [65]). Congruently, Grasha et al. [66] found that in the galaxy NGC 628, the clustering of star clusters decreases very rapidly with cluster age for OCs older than 0.04 Gyr. Therefore, we considered a simplified bimodal model where young OCs (<0.04 Gyr) have the above-derived probability of 71 ± 8% of forming part of a group and older OCs have a very low likelihood (~0) of being part of a group. When we applied this model to the total sample of clusters from Tarricq et al. [31] that have an estimated age (1315 clusters), counting the young clusters (229) separately, the result was an overall probability of (229/1315) 71 ± 8% = 12.4 ± 2% that any cluster is linked to another cluster. This value is remarkably close to the abovementioned average fraction of linked clusters in the Galaxy [9]. If we apply the same model to another updated catalogue [42], the result obtained is similar (16 ± 2%). In both cases, the quoted error estimates (2%) are scaled from the original probability (71 ± 8%) and rounded up. Therefore, a reasonable overall fraction of associated OCs is obtained by assuming that OCs younger than 0.04 Gyr are still most likely associated with their primordial relatives, while older OCs are most likely isolated as their siblings have been separated or disintegrated by tidal forces in the Galaxy and close encounters with giant molecular clouds [65]. Since the obtained figures are similar for the Galaxy and the Magellanic Clouds, we suggest that this mechanism could be general in disc galaxies where OCs are formed. Our findings agree, at least qualitatively, with those of [1] for ECs in the Galaxy (mentioned in the Introduction) and with the pioneering work of Larsen [67], who studied young OCs in nearby spiral galaxies. Larsen found that many of the youngest objects are in very crowded regions, and approximately $^{1}/_{3}$–$\frac{1}{2}$ of them are double or multiple sources.

6. The Double Cluster in Perseus and Other Reported Binary Cluster Candidates

As stated in the introduction, the classical double cluster formed by h and χ Persei (NGC 869 and NGC 884) was the only confirmed physical pair known in our Galaxy until recently. We reviewed their characteristics to see if they would also be considered an actual binary cluster according to our selection criteria. Based on the angular distance between both OC centres (27 arcmin), and assuming that they are at the same heliocentric distance (2.2 kpc; [34]), an estimated distance between them of ca. 20 pc can be inferred, well within the 100 pc limit that we used as a selection criterion. The median reported RV for NGC 869 (h Persei) is −42.8 km/s [28], and for NGC 884 (χ Persei) is −43 km/s [11,28,35], which are practically coincident. The Gaia DR2 mean parallaxes are 0.399 mas and 0.398 mas, respectively [34]. Thus, $\Delta plx/plx$ is less than 1%. Using PMs from Cantat-Gaudin et al. [34], $\Delta \mathrm{PM}/plx$ (and $\Delta \mathrm{PM}\ d$) is $\leq 0.2\ \mathrm{yr}^{-1}$. Consequently, the resulting orbital elements of both OCs are companionable within a 1σ deviation interval [31]. Therefore, it is clear that the binary system formed by NGC 869 and NGC 884 fulfills all our adopted criteria for a well-behaved binary system, but . . . what about the age?

According to the Primordial Group hypothesis, this physical pair should be of primordial origin, i.e., formed by young clusters of comparable age. For NGC 869, the extensive literature quotes ages from 3 Myr [55] to 19 Myr [41]. However, there is a broad consensus of a mean age of 12 Myr (e.g., [28,33,35,56,62,68]. NGC 884 has practically the same span of reported ages: from 3 Myr [64] to 18 Myr [34], but many reports converge near 13 Myr [28,33,35,57,58,68,69]. Therefore, both OCs are indeed young and have almost the same age within the observational error margins, as expected from the Primordial Group hypothesis.

Some other candidate binary clusters having at least one member older than 0.1 Gyr have been reported in the literature. We reexamine a few of them:

NGC 2383/NGC 2384

This pair was proposed as a probable binary cluster by [7]. Kopchev et al. [70] concluded that these two OCs were not born in the same molecular cloud, given their significant age difference.

Whatever the case, both NGC clusters do not appear to be physically associated, given their disparate characteristics (except for their close position in the sky). As detailed in Table 2, Gaia parallaxes and photometric distances agree that NGC 2383 is significantly farther away than NGC 2384. The ranges of reported RVs for both OCs do not overlap, confirming that they are not associated: RVs of NGC 2363 span from 55 km/s [71] to 72 km/s [31,43], while RVs of NGC 2364 range from 46 km/s (e.g., [24]) to 53 km/s [28,72]. Therefore, the diverse ages of this optical pair are not surprising, even though a minimum age of 15 Myr has also been reported for NGC 2383 [56].

NGC 2384 is quite elongated [40] and has an extended halo (at least 40 arcmin) beyond its reported radius towards the north. Incidentally, this halo (encompassing NGC 2384) has been identified as the new OC UBC 224 [34]. Most reported ages range from 0.006 Gyr [55] to 0.021 Myr [43], i.e., it is a young OC by any standards. Unexpectedly, a new OC with compatible parameters was found while studying the star field around NGC 2384. This cluster, Casado 73, seems somewhat older (0.08 Gyr), but it is also a young OC. The mean parallaxes of NGC 2384 and Casado 73 are somewhat discrepant (Table 2), but Gaia parallaxes of 0.33 mas [43] and 0.35 mas [42] for NGC 2384 alleviate this discrepancy. These parallaxes are compatible with the photometric distance of Casado 73 (3.1 kpc), which in turn is harmonious with its Gaia EDR3 parallax. Moreover, that distance is within the range of most reported photometric distances for NGC 2384: from 2.1 kpc (e.g., [35]) to 3.2 kpc (e.g., [61]). Furthermore, their CMDs show a coincident main sequence suggesting similar distance, age, and metallicity (Figure 5). The estimated extinction of this new OC is A_V = 0.51 mag. The data ensemble indicates that this is a plausible primordial pair (Group O), even though no RVs were found for the member stars of Casado 73. Regardless, this primordial pair candidate requires confirmation.

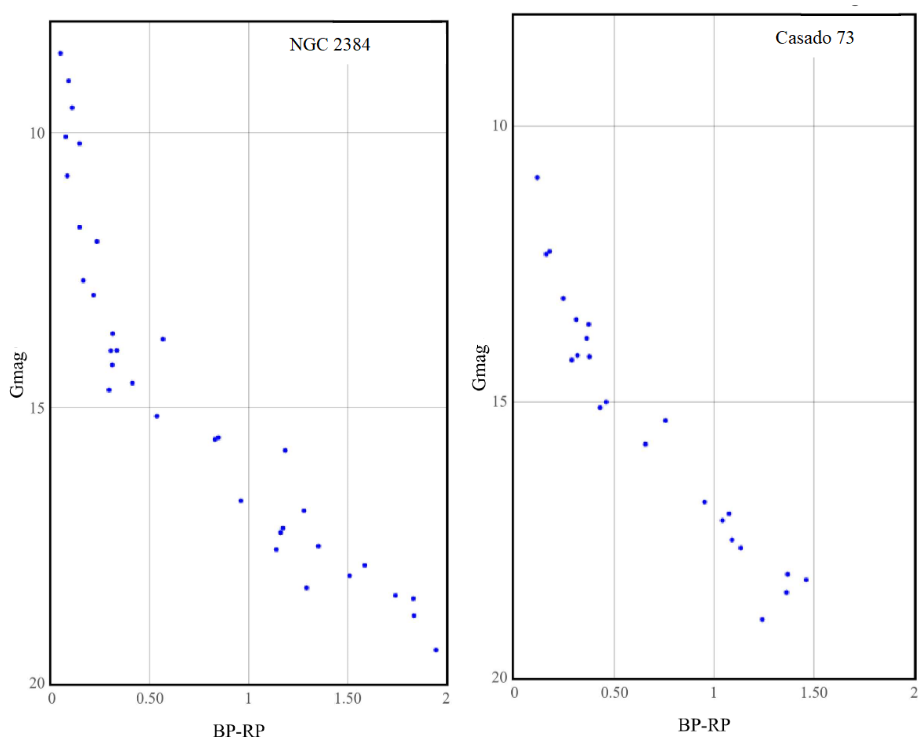

Figure 5. Comparison of CMD plots for the candidate primordial pair formed by NGC 2384 and Casado 73. Constraints for each OC are given in Table 2.

FSR 1767/Ruprecht 127

De la Fuente Marcos et al. [73] proposed this pair of star clusters to be the result of the capture of Ruprecht 127 by the candidate globular cluster FSR 1767 (2MASS-GC04) [74]. Although FSR 1767 has been described as an OC using Gaia EDR3 [42], no other Gaia studies related to it were retrieved (see comment on pair #16b), and we did not find any trace of such a cluster in Gaia data. Previous literature only reported a single intermediate age (0.473 Gyr), although frequently repeated (e.g., [28,32,41,42], and two discordant photometric distances: 1948 pc (e.g., [28,32,41] and 3.6 kpc [63]. The number of reported member stars also varies greatly: from 17 (e.g., [28]) to 984 [75]. All these conflicting results make very doubtful the physical existence of such an OC, in which case no binary cluster containing FSR 1767 would exist.

Last but not least, all the likely binary clusters lately proposed by Soubiran et al. [11] using Gaia data, namely ASCC 16/ASCC21, Collinder 140/NGC 2451B, IC 2602/Platais 8, RSG7/RSG 8, and Collinder 394/NGC 6716, appear to be young ($\leq$0.1 Gyr) and have ages compatible with a common origin. Their group of five members containing ASCC 16, ASCC 19, ASCC 21, Gulliver 6, and NGC 2232 also follows the same rules and, thus, appears to form a primordial group.

7. Concluding Remarks

In this work, we formulated and tested the Primordial Group hypothesis, which states that OCs are born in primordial groups that disperse through the galactic disc in a relatively short time ($\leq$0.1 Gyr). We tested that hypothesis through manual mining of Gaia EDR3 and careful review of the extensive literature concerning OCs.

The review of candidate pairs in DFM with at least one of their members older than 0.1 Gyr allowed us to conclude that practically all of them can be discarded as actual binary clusters. Some of the pairs are optical pairs, others are hyperbolic encounters, and a few pairs may be primordial pairs with flawed ages. A significant number of the clusters studied in this sample are most likely false OCs: Loden 1171, ASCC 34, Loden 565, VdBH 91, ASCC 4, NGC 1746, Basel 5, Loden 165, ESO 128-16 and ESO 132-14.

We revisited the twenty youngest OCs (<0.01 Gyr) listed by Tarricq et al. [31], looking for associated clusters closer than 100 pc and sharing PMs and RVs. The resulting statistics suggest that the probability that young OCs have related siblings is 71 $\pm$ 8%. On the other hand, the probability that older OCs (>4 Gyr) from the same catalogue are not alone seems very low, if not zero. A reasonable overall fraction of associated OCs (12–16%) can be obtained from a simplified bimodal model, which assumes that OCs younger than 0.04 Gyr are still most likely associated with their primordial relatives, while older OCs are most likely isolated. However, these proportions are only approximate due to the incompleteness of the sample.

Seven new OCs were identified during this research (namely, Casado 67–73). This unexpected result reveals that the search for associated clusters around very young stellar clusters is an effective method for discovering new OCs, as is the search for new OCs around a given grouping [9].

The classical double cluster in Perseus fulfills all our selection criteria for a binary system. Both members are indeed young (<0.02 Gyr) and are of practically the same age, as expected from the tested hypothesis. Some other reported binary cluster candidates with putative members greater than 0.1 Gyr were reasonably discarded. On the other hand, the likely OC groups from Soubiran et al. [11] are young and compatible with the Primordial Group hypothesis.

Three of the revised OCs (UBC 224, UBC 323 and UBC 344; [15]) were found to encompass a significant number of member stars of other well-known OCs.

The present results indicate that the vast majority of real double/multiple OCs in the Galaxy, if not all, are of primordial origin and are not stable for a long time, in line with similar conclusions obtained from study of the Magellanic Clouds [8,19]. Thus, the pairs of OCs in these groups are generally not true binary systems since they are not gravitationally bound. The Primordial Group hypothesis has successfully passed these four tests and, therefore, deserves further scrutiny as a feasible working model.

Funding: This research received no external funding.

Data Availability Statement: The data associated with this manuscript are available in the public data repositories mentioned in the Acknowledgements section and in the referenced studies.

Acknowledgments: The author is indebted to David Jou for his longstanding support and encouraging discussions. Thanks to Friedrich Anders and Alfred Castro Ginard for providing photometric distances and ages of some of the new OCs found in this study. This work made use of data from the European Space Agency (ESA) mission Gaia (https://www.cosmos.esa.int/Gaia, accessed on 7 October 2021), processed by the Gaia Data Processing and Analysis Consortium (DPAC, https://www.cosmos.esa.int/web/Gaia/dpac/consortium, accessed on 7 October 2021). Funding for the DPAC was provided by national institutions, in particular the institutions participating in the Gaia Multilateral Agreement. This research made extensive use of the SIMBAD database and the VizieR catalogue access tool, operating at the CDS, Strasbourg, France (DOI: 10.26093/cds/vizier), and of NASA Astrophysics Data System Bibliographic Services.

Conflicts of Interest: The author declares no conflict of interest.

References

1. Bica, E.; Dutra, C.M.; Barbuy, B. A Catalogue of infrared star clusters and stellar groups. *Astron. Astrophys.* **2003**, *397*, 177–180. [CrossRef]
2. Camargo, D.; Bica, E.; Bonatto, C. Characterizing star cluster formation with WISE: 652 newly found star clusters and candidates. *Mon. Not. R. Astron. Soc.* **2016**, *455*, 3126–3135. [CrossRef]
3. Rozhavskii, F.G.; Kuz'mina, V.A.; Vasilevskii, A.E. Statistical approach toward determining the multiplicity of open stellar clusters. *Astrophysics* **1976**, *12*, 204–209. [CrossRef]
4. Vázquez, R.A.; Moitinho, A.; Carraro, G.; Dias, W.S. Open clusters in the Third Galactic Quadrant III. Alleged binary clusters. *Astron. Astrophys.* **2010**, *511*, A38. [CrossRef]
5. de La Fuente Marcos, R.; de La Fuente Marcos, C. Double or binary: On the multiplicity of open star clusters. *Astron. Astrophys.* **2009**, *500*, L13–L16. [CrossRef]
6. Piskunov, A.E.; Kharchenko, N.V.; Röser, S.; Schilbach, E.; Scholz, R.D. Revisiting the population of Galactic open clusters. *Astron. Astrophys.* **2006**, *445*, 545–565. [CrossRef]
7. Subramaniam, A.; Gorti, U.; Sagar, R.; Bhatt, H.C. Probable binary open star clusters in the Galaxy. *Astron. Astrophys.* **1995**, *302*, 86.
8. Dieball, A.; Müller, H.; Grebel, E.K. A statistical study of binary and multiple clusters in the LMC. *Astron. Astrophys.* **2002**, *391*, 547–564. [CrossRef]
9. Casado, J. The list of possible double and multiple open clusters between galactic longitudes 240 and 270 degrees. *Astron. Rep.* **2021**, *65*, 755–775. [CrossRef]
10. de La Fuente Marcos, R.; de La Fuente Marcos, C. The Evolution of Primordial Binary Open Star Clusters: Mergers, Shredded Secondaries, and Separated Twins. *Astrophys. J.* **2010**, *719*, 104. [CrossRef]
11. Soubiran, C.; Cantat-Gaudin, T.; Romero-Gomez, M.; Casamiquela, L.; Jordi, C.; Vallenari, A.; Antoja, T.; Balaguer-Núñez, L.; Bossini, D.; Bragaglia, A.; et al. Open cluster kinematics with Gaia DR2. *Astron. Astrophys.* **2018**, *619*, A155, Erratum in *Astron. Astrophys.* **2019**, *623*, C2. [CrossRef]
12. Brown, A.; Vallenari, A.; Prusti, T.; De Bruijne, J.; Babusiaux, C.; Biermann, M.; Creevey, O.; Evans, D.; Eyer, L.; Hutton, A.; et al. Gaia Data Release 2 Summary of the contents and survey properties. *Astron. Astrophys.* **2018**, *616*, A1.
13. Brown, A.G.A.; Vallenari, A.; Prusti, T.; de Bruijne, J.H.J.; Babusiaux, C.; Biermann, M.; Creevey, O.L.; Evans, D.W.; Eyer, L.; Hutton, A.; et al. Gaia Early Data Release 3: Summary of the contents and survey properties. *arXiv* **2020**, arXiv:2012.01533.
14. Cantat-Gaudin, T.; Jordi, C.; Vallenari, A.; Bragaglia, A.; Balaguer-Núñez, L.; Soubiran, C.; Bossini, D.; Moitinho, A.; Castro-Ginard, A.; Krone-Martins, A.; et al. A Gaia DR2 view of the open cluster population in the Milky Way. *Astron. Astrophys.* **2018**, *618*, A93. [CrossRef]
15. Castro-Ginard, A.; Jordi, C.; Luri, X.; Cid-Fuentes, J.Á.; Casamiquela, L.; Anders, F.; Cantat-Gaudin, T.; Monguió, M.; Balaguer-Nuñez, L.; Solà, S. Hunting for open clusters in Gaia DR2: 582 new open clusters in the Galactic disc. *Astron. Astrophys.* **2020**, *635*, A45. [CrossRef]
16. Cantat-Gaudin, T.; Anders, F. Clusters and mirages: Cataloguing stellar aggregates in the Milky Way. *Astron. Astrophys.* **2020**, *633*, A99. [CrossRef]
17. Hunt, E.L.; Reffert, S. Improving the open cluster census-I. Comparison of clustering algorithms applied to Gaia DR2 data. *Astron. Astrophys.* **2021**, *646*, A104. [CrossRef]
18. Casado, J. New Open Clusters Found by Manual Mining of Data Based in Gaia DR2. *Res. Astron. Astrophys.* **2020**, *21*, 117. [CrossRef]
19. Hatzidimitriou, D.; Bhatia, R.K. Cluster pairs in the Small Magellanic Cloud. *Astron. Astrophys.* **1990**, *230*, 11–15.
20. Cantat-Gaudin, T.; Jordi, C.; Wright, N.J.; Armstrong, J.J.; Vallenari, A.; Balaguer-Núñez, L.; Ramos, P.; Bossini, D.; Padoan, P.; Pelkonen, V.M.; et al. Expanding associations in the Vela-Puppis region-3D structure and kinematics of the young population. *Astron. Astrophys.* **2019**, *626*, A17. [CrossRef]
21. de la Fuente Marcos, R.; de la Fuente Marcos, C. Hierarchical star formation in the Milky Way disk. *Astrophys. J.* **2009**, *700*, 436. [CrossRef]
22. Grasha, K.; Elmegreen, B.G.; Calzetti, D.; Adamo, A.; Aloisi, A.; Bright, S.N.; Cook, D.O.; Dale, D.A.; Fumagalli, M.; Iii, J.S.G.; et al. Hierarchical star formation in turbulent media: Evidence from young star clusters. *Astrophys. J.* **2017**, *842*, 25. [CrossRef]
23. Kounkel, M.; Covey, K. Untangling the Galaxy. I. Local Structure and Star Formation History of the Milky Way. *Astron. J.* **2019**, *158*, 122. [CrossRef]
24. Conrad, C.; Scholz, R.D.; Kharchenko, N.V.; Piskunov, A.E.; Röser, S.; Schilbach, E.; de Jong, R.S.; Schnurr, O.; Steinmetz, M.; Grebel, E.K.; et al. A RAVE investigation on Galactic open clusters-II. Open cluster pairs, groups and complexes. *Astron. Astrophys.* **2017**, *600*, A106. [CrossRef]
25. Liu, L.; Pang, X. A catalog of newly identified star clusters in GAIA DR2. *Astrophys. J. Suppl. Ser.* **2019**, *245*, 32. [CrossRef]
26. Paunzen, E.; Netopil, M. On the current status of open-cluster parameters. *Mon. Not. R. Astron. Soc.* **2006**, *371*, 1641–1647. [CrossRef]
27. Mermilliod, J.C.; Paunzen, E. Analysing the database for stars in open clusters-I. General methods and description of the data. *Astron. Astrophys.* **2003**, *410*, 511–518. [CrossRef]

28. Dias, W.S.; Alessi, B.S.; Moitinho, A.; Lépine, J.R.D. New catalogue of optically visible open clusters and candidates. *Astron. Astrophys.* **2002**, *389*, 871–873. [CrossRef]
29. Lindegren, L.; Hernández, J.; Bombrun, A.; Klioner, S.; Bastian, U.; Ramos-Lerate, M.; de Torres, A.; Steidelmuller, H.; Stephenson, C.; Hobbs, D.; et al. Gaia data release 2-the astrometric solution. *Astron. Astrophys.* **2018**, *616*, A2. [CrossRef]
30. Kharchenko, N.V.; Piskunov, A.E.; Röser, S.; Schilbach, E.; Scholz, R.D. Astrophysical parameters of Galactic open clusters. *Astron. Astrophys.* **2005**, *438*, 1163–1173. [CrossRef]
31. Tarricq, Y.; Soubiran, C.; Casamiquela, L.; Cantat-Gaudin, T.; Chemin, L.; Anders, F.; Antoja, T.; Romero-Gómez, M.; Figueras, F.; Jordi, C.; et al. 3D kinematics and age distribution of the open cluster population. *Astron. Astrophys.* **2021**, *647*, A19. [CrossRef]
32. Dib, S.; Schmeja, S.; Parker, R.J. Structure and mass segregation in Galactic stellar clusters. *Mon. Not. R. Astron. Soc.* **2018**, *473*, 849–859. [CrossRef]
33. Vande Putte, D.; Garnier, T.P.; Ferreras, I.; Mignani, R.P.; Cropper, M. A kinematic study of open clusters: Implications for their origin. *Mon. Not. R. Astron. Soc.* **2010**, *407*, 2109–2121. [CrossRef]
34. Cantat-Gaudin, T.; Anders, F.; Castro-Ginard, A.; Jordi, C.; Romero-Gómez, M.; Soubiran, C.; Casamiquela, L.; Tarricq, Y.; Moitinho, A.; Vallenari, A.; et al. Painting a portrait of the Galactic disc with its stellar clusters. *Astron. Astrophys.* **2020**, *640*, A1. [CrossRef]
35. Loktin, A.V.; Popova, M.E. Updated version of the 'homogeneous catalog of open cluster parameters'. *Astrophys. Bull.* **2017**, *72*, 257–265. [CrossRef]
36. Dias, W.S.; Monteiro, H.; Caetano, T.C.; Lépine, J.R.D.; Assafin, M.; Oliveira, A.F. Proper motions of the optically visible open clusters based on the UCAC4 catalog. *Astron. Astrophys.* **2014**, *564*, A79. [CrossRef]
37. Zejda, M.; Paunzen, E.; Baumann, B.; Mikulášek, Z.; Liška, J. Catalogue of variable stars in open cluster fields. *Astron. Astrophys.* **2012**, *548*, A97. [CrossRef]
38. Kharchenko, N.V.; Berczik, P.; Petrov, M.I.; Piskunov, A.E.; Röser, S.; Schilbach, E.; Scholz, R.D. Shape parameters of Galactic open clusters. *Astron. Astrophys.* **2009**, *495*, 807–818. [CrossRef]
39. Joshi, Y.C.; Dambis, A.K.; Pandey, A.K.; Joshi, S. Study of open clusters within 1.8 kpc and understanding the Galactic structure. *Astron. Astrophys.* **2016**, *593*, A116. [CrossRef]
40. Bica, E.; Pavani, D.B.; Bonatto, C.J.; Lima, E.F. A Multi-band Catalog of 10978 Star Clusters, Associations, and Candidates in the Milky Way. *Astron. J.* **2019**, *157*, 12. [CrossRef]
41. Kharchenko, N.V.; Piskunov, A.E.; Schilbach, E.; Röser, S.; Scholz, R.D. Global survey of star clusters in the Milky Way-II. The catalogue of basic parameters. *Astron. Astrophys.* **2013**, *558*, A53. [CrossRef]
42. Hao, C.J.; Xu, Y.; Hou, L.G.; Bian, S.B.; Li, J.J.; Wu, Z.Y.; He, Z.H.; Li, Y.J.; Liu, D.J. Evolution of the local spiral structure of the Milky Way revealed by open clusters. *Astron. Astrophys.* **2021**, *652*, A102. [CrossRef]
43. Dias, W.S.; Monteiro, H.; Moitinho, A.; Lépine, J.R.D.; Carraro, G.; Paunzen, E.; Alessi, B.; Villela, L. Updated parameters of 1743 open clusters based on Gaia DR2. *Mon. Not. R. Astron. Soc.* **2021**, *504*, 356–371. [CrossRef]
44. Morales, E.F.; Wyrowski, F.; Schuller, F.; Menten, K.M. Stellar clusters in the inner Galaxy and their correlation with cold dust emission. *Astron. Astrophys.* **2013**, *560*, A76. [CrossRef]
45. Battinelli, P.; Brandimarti, A.; Capuzzo-Dolcetta, R. Integrated photometric properties of open clusters. *arXiv* **1994**, arXiv:astro-ph/9406025.
46. Perren, G.I.; Giorgi, E.E.; Moitinho, A.; Carraro, G.; Pera, M.S.; Vázquez, R.A. Sixteen overlooked open clusters in the fourth Galactic quadrant-A combined analysis of UBVI photometry and Gaia DR2 with ASteCA. *Astron. Astrophys.* **2020**, *637*, A95. [CrossRef]
47. Zhong, J.; Chen, L.; Wu, D.; Li, L.; Bai, L.; Hou, J. Exploring open cluster properties with Gaia and LAMOST. *Astron. Astrophys.* **2020**, *640*, A127. [CrossRef]
48. Yalyalieva, L.; Carraro, G.; Vazquez, R.; Rizzo, L.; Glushkova, E.; Costa, E. A new look at Sco OB1 association with Gaia DR2. *Mon. Not. R. Astron. Soc.* **2020**, *495*, 1349–1359. [CrossRef]
49. Bossini, D.; Vallenari, A.; Bragaglia, A.; Cantat-Gaudin, T.; Sordo, R.; Balaguer-Núñez, L.; Jordi, C.; Moitinho, A.; Soubiran, C.; Casamiquela, L.; et al. Age determination for 269 Gaia DR2 open clusters. *Astron. Astrophys.* **2019**, *623*, A108. [CrossRef]
50. Carraro, G.; Patat, F.; Baumgardt, H. Star clusterings in the Carina complex: Photometry of NGC 3324 and Loden 165. *Astron. Astrophys.* **2001**, *371*, 107–114. [CrossRef]
51. Buckner, A.S.; Froebrich, D. Properties of star clusters–II. Scaleheight evolution of clusters. *Mon. Not. R. Astron. Soc.* **2014**, *444*, 290–302. [CrossRef]
52. De Silva, G.M.; Carraro, G.; D'Orazi, V.; Efremova, V.; Macpherson, H.; Martell, S.; Rizzo, L. Binary open clusters in the Milky Way: Photometric and spectroscopic analysis of NGC 5617 and Trumpler 22. *Mon. Not. R. Astron. Soc.* **2015**, *453*, 106–112. [CrossRef]
53. Mercer, E.P.; Clemens, D.P.; Meade, M.R.; Babler, B.; Indebetouw, R.; Whitney, B.A.; Watson, C.; Wolfire, M.G.; Wolff, M.J.; Bania, T.M.; et al. New star clusters discovered in the GLIMPSE survey. *Astrophys. J.* **2005**, *635*, 560. [CrossRef]
54. Monteiro, H.; Dias, W.S.; Moitinho, A.; Cantat-Gaudin, T.; Lépine, J.R.; Carraro, G.; Paunzen, E. Fundamental parameters for 45 open clusters with Gaia DR2, an improved extinction correction and a metallicity gradient prior. *Mon. Not. R. Astron. Soc.* **2020**, *499*, 1874–1889. [CrossRef]
55. Dambis, A.K. Space-age distribution of young open clusters and observational selection. *Astron. Lett.* **1999**, *25*, 10–17.
56. Ahumada, J.A.; Lapasset, E. New catalogue of blue stragglers in open clusters. *Astron. Astrophys.* **2007**, *463*, 789–797. [CrossRef]

57. Gozha, M.L.; Borkova, T.V.; Marsakov, V.A. Heterogeneity of the population of open star clusters in the Galaxy. *Astron. Lett.* **2012**, *38*, 506–518. [CrossRef]
58. Wu, Z.Y.; Zhou, X.; Ma, J.; Du, C.H. The orbits of open clusters in the Galaxy. *Mon. Not. R. Astron. Soc.* **2009**, *399*, 2146–2164. [CrossRef]
59. Donor, J.; Frinchaboy, P.M.; Cunha, K.; O'Connell, J.E.; Prieto, C.A.; Almeida, A.; Anders, F.; Beaton, R.; Bizyaev, D.; Brownstein, J.R.; et al. The Open Cluster Chemical Abundances and Mapping Survey. IV. Abundances for 128 Open Clusters Using SDSS/APOGEE DR16. *Astron. J.* **2020**, *159*, 199. [CrossRef]
60. Wouterloot, J.G.A.; Brand, J. IRAS sources beyond the solar circle. I-CO observations. *Astron. Astrophys. Suppl. Ser.* **1989**, *80*, 149–187.
61. Glushkova, E.V.; Zabolotskikh, M.V.; Rastorguev, A.S.; Uglova, I.M.; Fedorova, A.A. Absolute proper motions of 181 young open clusters. *Astron. Lett.* **1997**, *23*, 71–78.
62. Loktin, A.V.; Matkin, N.V. The characteristics of open star clusters from UBV data. *Astron. Astrophys. Trans.* **1994**, *4*, 153–165. [CrossRef]
63. Buckner, A.S.; Froebrich, D. Properties of star clusters–I. Automatic distance and extinction estimates. *Mon. Not. R. Astron. Soc.* **2013**, *436*, 1465–1478. [CrossRef]
64. Ahumada, J.; Lapasset, E. Catalogue of blue stragglers in open clusters. *Astron. Astrophys. Suppl. Ser.* **1995**, *109*, 375–382. [CrossRef]
65. Bhatia, R.K. Merger and disruption lifetimes of binary star clusters in the Large Magellanic Cloud. *Publ. Astron. Soc. Jpn.* **1990**, *42*, 757–767.
66. Grasha, K.; Calzetti, D.; Adamo, A.; Kim, H.; Elmegreen, B.G.; Gouliermis, D.A.; Wofford, A. The spatial distribution of the young stellar clusters in the star-forming galaxy NGC 628. *Astrophys. J.* **2015**, *815*, 93. [CrossRef]
67. Larsen, S.S. The structure and environment of young stellar clusters in spiral galaxies. *Astron. Astrophys.* **2004**, *416*, 537–553. [CrossRef]
68. Rain, M.J.; Ahumada, J.A.; Carraro, G. A new, Gaia-based, catalogue of blue straggler stars in open clusters. *Astron. Astrophys.* **2021**, *650*, A67. [CrossRef]
69. Hayes, C.R.; Friel, E.D. Radial velocities of three poorly studied clusters and the kinematics of open clusters. *Astron. J.* **2014**, *147*, 69. [CrossRef]
70. Kopchev, V.; Nedialkov, P.; Petrov, G. Age determination of possible binary open clusters NGC 2383/NGC 2384 and Pismis 6/Pismis 8. *arXiv* **2008**, arXiv:0808.4055.
71. Huang, W.; Gies, D.R. Stellar rotation in young clusters. I. Evolution of projected rotational velocity distributions. *Astrophys. J.* **2006**, *648*, 580. [CrossRef]
72. Garmany, C.D.; Glaspey, J.W.; Bragança, G.A.; Daflon, S.; Fernandes, M.B.; Oey, M.S.; Bensby, T.; Cunha, K. Projected Rotational Velocities of 136 Early B-type Stars in the Outer Galactic Disk. *Astron. J.* **2015**, *150*, 41. [CrossRef]
73. de la Fuente Marcos, R.; de la Fuente Marcos, C.; Reilly, D. Gravitational interactions between globular and open clusters: An introduction. *Astrophys. Space Sci.* **2014**, *349*, 379–400. [CrossRef]
74. Bonatto, C.; Bica, E.; Ortolani, S.; Barbuy, B. FSR1767–a new globular cluster in the Galaxy. *Mon. Not. R. Astron. Soc. Lett.* **2007**, *381*, L45–L49. [CrossRef]
75. Froebrich, D.; Scholz, A.; Raftery, C.L. A systematic survey for infrared star clusters with $|b| < 20°$ using 2MASS. *Monthly Mon. Not. R. Astron. Soc.* **2007**, *374*, 399–408.