A detailed analysis of the most distant catalogued open clusters

Re-assessing fundamental parameters with Gaia EDR3 and `ASteCA`

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ABSTRACT

Context. Several studies have been presented in the last few years applying some kind of automatic processing of data to estimate the fundamental parameters of open clusters. These parameters are later on employed in larger scale analyses, for example the structure of the Galaxy's spiral arms. The distance is one of the more straightforward parameters to estimate, yet enormous differences can still be found among published data. This is particularly true for open clusters located more than a few Kpc away.
Aims. We cross-matched several published catalogues and selected the twenty-five most distant open clusters (>9000 Kpc). We then performed a detailed analysis of their fundamental parameters, with emphasis on their distances, to determine the agreement between catalogues and our estimates.
Methods. Photometric and astrometric data from the Gaia EDR3 survey was employed. The data was processed with our own membership analysis code (pyUPMASK), and our package for automatic fundamental cluster's parameters estimation (`ASteCA`).
Results. We find differences in the estimated distances of up to several Kpc between our results and those catalogued, even for the catalogues that show the best matches with `ASteCA` values. Large differences are also found for the age estimates.
Conclusions. Caution is thus strongly recommended when using catalogued parameters of open clusters to infer large-scale properties of the Galaxy, particularly for those located more than a few Kpc away.

Key words. Methods: statistical – Galaxies: star clusters: general – (Galaxy:) open clusters and associations: general – Techniques: photometric– Parallaxes – Proper motions

1. Introduction

Open clusters (OCs) are not only used as laboratories to investigate stellar evolution, they are also routinely employed in the analysis of the Milky Way's structure (Loktin & Matkin 1992; Moitinho et al. 2006; Vázquez et al. 2008; Moitinho 2010). Young OCs for example are known to be particularly useful in the tracing of spiral arms, as they have not yet drifted too far from their birth position (Carraro 2013; Molina Lera et al. 2018). As deeper, more complete, and more precise photometric and astrometric data becomes available, these studies will inevitably be extended towards more distant regions of the Galaxy.

AGREGARCONTENIDO ACA

This article is structured as follows. In Sect 2 we introduce the stellar cluster catalogues, the clusters selected to be analyzed (crossed-matched from those catalogues), and the photometric and astrometric data used to perform the analysis. Sect 3 presents the methods employed in the study of all the clusters. The comparison of the estimated parameters with the catalogued values for each cluster is done in Sect 4. Finally, conclusions are highlighted in Sect 5.

2. Catalogues, clusters, and data

We chose four catalogues to cross-match and subsequently select the most distant clusters: Dias et al. (2002, New Catalog of Optically Visible Open Clusters and Candidates, hereinafter OC), Netopil et al. (2012, WEBDA,[1] hereinafter WB), Kharchenko et al. (2012, Milky Way Star Clusters Catalog, hereinafter MW), and Cantat-Gaudin et al. (2020, hereinafter CG). The first two (OC and WB) are compilations of open clusters' fundamental parameters from the literature. They contain around 1700 (WB) and 2100 (OC) entries, and are heavily used in the field of open cluster research. The parameter values in both catalogues are heterogeneous, being compiled from various sources. The MW catalog is the largest one (~3000 entries) and, similarly to the CG catalog (~2000 entries), is composed of homogeneous fundamental parameter values obtained for all its entries. The method employed by the authors of the MW catalog is a semi-automated isochrone fit, while the CG catalog was generated employing an artificial neural network (trained on parameter values taken from the literature).

Since we are interested in the open clusters most distant from the Sun, we select from these cross-matched catalogues those that are located at a distance of 9 Kpc or more in either of them. This is an arbitrary value that results in enough clusters to draw general conclusions, but not too many that would impede their detailed analysis. The initial full list consisted of thirty-eight open clusters. Eleven of these were found only in the MW catalog with distances larger than 9000 pc. These are either listed with substantially smaller distances in the other cat-

[1] https://webda.physics.muni.cz/

alogs, or too sparse and or dubious. Hence these clusters were removed from the cross-matched list. Two other clusters were also removed: Shorlin 1 (α_{2000}=166.44, δ_{2000}=-61.23) and FSR0338 (α_{2000}=327.93, δ_{2000}=55.33). The latter appears in WB and MW at a distance of 12600 pc and 5600 pc respectively, while the former is listed only in MW with a distance of 14655 pc. Shorlin1 is studied in Carraro & Costa (2009) and Turner (2012); in both cases the authors conclude that this is not a real cluster but a grouping of young stars. FSR0338 is analyzed in Froebrich et al. (2010) where a distance of 6000 pc is assigned, but with large uncertainties. In both cases we find no evidence of a true stellar cluster in these regions. We base our conclusion on two findings. First, the large proper motions dispersion of the stars that occupy the overdensity around the central coordinates assigned to either object. Second, the lack of a clear sequence in their respective color-magnitude diagrams (CMD). These two clusters are thus discarded from further analysis. The remaining twenty-five clusters that will be studied in this work are shown in Table 1. Most of the selected clusters are located in the Third Quadrant with all of them in the latitude range of [-12°, 8°], relatively close to the galactic plane.

There are two other major works where a large catalog of analyzed open clusters is presented: Liu & Pang (2019) and Dias et al. (2021). The latter does not contain clusters with such large distances, and was hence not used. The former lists only four, and their values will be included in the discussion of the results in Sect. 4.

Data from Gaia EDR3 (Gaia Collaboration et al. 2016, 2021) was retrieved for a box of 20 arcmin of length around the central coordinates for all the clusters. A small synopsis for each cluster is presented below, in alphabetical order:

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Table 1. Selected catalogued open clusters with a distance ≥9000 pc, ordered by right ascension. The ages are expressed as the logarithm, and the distances are in parsec. In parenthesis, the short names used for the clusters throughout the article. Clusters with no distances below the 9000 pc limit in any of the catalogs are marked with boldface.

Cluster	α_{2000}	δ_{2000}	OC_{age}	OC_{dist}	CG_{age}	CG_{dist}	WB_{age}	WB_{dist}	MW_{age}	MW_{dist}
Berkeley 73 (BER73)	95.5	-6.35	9.18	9800	9.15	6158	9.36	6850	9.15	7881
Berkeley 25 (BER25)	100.25	-16.52	9.7	11400	9.39	6780	9.6	11300	9.7	11400
Berkeley 75 (BER75)	102.25	-24	9.6	9100	9.23	8304	9.48	9800	9.3	6273
Berkeley 26 (BER26)	102.58	5.75	9.6	12589	-	-	9.6	4300	8.71	2724
Berkeley 29 (**BER29**)	103.27	16.93	9.025	14871	9.49	12604	9.025	14871	9.1	10797
Tombaugh 2 (TOMB2)	105.77	-20.82	9.01	6080	9.21	9316	9.01	13260	9.01	6565
Berkeley 76 (BER76)	106.67	-11.73	9.18	12600	9.22	4746	9.18	12600	8.87	2360
FSR 1212 (F1212)	106.94	-14.15	-	-	9.14	9682	-	-	8.65	1780
Saurer 1 (**SAU1**)	110.23	1.81	9.7	13200	-	-	9.85	13200	9.6	13719
Czernik 30 (CZER30)	112.83	-9.97	9.4	9120	9.46	6647	9.4	6200	9.2	6812
Arp-Madore 2 (**ARPM2**)	114.69	-33.84	9.335	13341	9.48	11751	9.335	13341	9.335	13338
vd Bergh-Hagen 4 (**BH4**)	114.43	-36.07	-	-	-	-	8.3	19300	-	-
FSR 1419 (F1419)	124.71	-47.79	-	-	9.21	11165	-	-	8.375	7746
vd Bergh-Hagen 37 (BH37)	128.95	-43.62	8.84	11220	8.24	4038	8.85	2500	7.5	5202
ESO 092 05 (E9205)	150.81	-64.75	9.3	5168	9.65	12444	9.78	10900	9.3	5168
ESO 092 18 (E9218)	153.74	-64.61	9.024	10607	9.46	9910	9.024	607	9.15	9548
Saurer 3 (SAU3)	160.35	-55.31	9.3	9550	-	-	9.45	8830	9.3	7075
Kronberger 39 (KRON39)	163.56	-61.74	-	11100	-	-	-	-	6	4372
ESO 093 08 (E9308)	169.92	-65.22	9.74	14000	-	-	9.65	3700	9.8	13797
vd Bergh-Hagen 144 (BH144)	198.78	-65.92	8.9	12000	9.17	9649	8.9	12000	9	7241
vd Bergh-Hagen 176 (BH176)	234.85	-50.05	-	-	-	-	-	13400	9.8	18887
Kronberger 31 (**KRON31**)	295.05	26.26	-	11900	-	-	-	-	8.5	12617
Saurer 6 (SAU6)	297.76	32.24	9.29	9330	-	-	9.29	9330	9.2	7329
Berkeley 56 (**BER56**)	319.43	41.83	9.6	12100	9.47	9516	9.6	12100	9.4	13180
Berkeley 102 (BER102)	354.66	56.64	9.5	9638	9.59	10519	8.78	2600	9.14	4900

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Kronberger31 and **Kronberger39**: these two clusters where discovered and catalogued as *Cluster candidates with RCs* in Kronberger et al. (2006). Both show a very dispersed and scarcely populated sequence.

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Table 2. xxx

Cluster	r_c	r_t	radius
BER73	$0.6^{0.7}_{0.5}$	$4.9^{6.3}_{3.8}$	2.0
BER25	$1.5^{1.8}_{1.2}$	$7.0^{8.0}_{6.2}$	5.0
BER75	$0.4^{0.5}_{0.3}$	$5.0^{6.6}_{3.6}$	2.0
BER26	$0.7^{1.0}_{0.5}$	$3.4^{4.5}_{2.5}$	1.6
BER29	$0.5^{0.5}_{0.4}$	$7.4^{8.6}_{6.4}$	3.0
TOMB2	$0.9^{0.9}_{0.8}$	$6.7^{7.4}_{6.1}$	3.5
BER76	$1.6^{2.5}_{1.2}$	$7.4^{9.6}_{5.7}$	4.0
F1212	$0.8^{1.1}_{0.6}$	$8.8^{10.7}_{6.6}$	3.0
SAU1	$0.7^{1.0}_{0.5}$	$3.9^{5.4}_{2.9}$	2.0
CZER30	$0.6^{0.7}_{0.4}$	$6.4^{8.2}_{4.8}$	2.5
ARPM2	$1.4^{2.0}_{1.0}$	$4.1^{4.9}_{3.4}$	3.0
BH4	$0.4^{0.5}_{0.3}$	$5.7^{7.1}_{4.0}$	2.0
F1419	$1.2^{1.8}_{0.9}$	$6.0^{8.3}_{4.3}$	3.0
BH37	$1.2^{1.9}_{0.8}$	$3.8^{5.6}_{2.5}$	2.0
E9205	$1.0^{1.3}_{0.9}$	$4.4^{5.3}_{3.7}$	3.0
E9218	$0.6^{0.7}_{0.6}$	$6.5^{7.3}_{5.9}$	3.0
SAU3	$0.5^{0.6}_{0.4}$	$4.9^{6.4}_{3.8}$	2.0
KRON39	$0.3^{0.3}_{0.2}$	$5.6^{7.0}_{4.1}$	2.0
E9308	$0.2^{0.2}_{0.2}$	$5.0^{5.7}_{4.2}$	1.5
BH144	$0.3^{0.4}_{0.3}$	$2.8^{3.4}_{2.3}$	1.5
BH176	$0.6^{0.7}_{0.5}$	$4.6^{5.8}_{3.8}$	2.0
KRON31	$0.5^{0.6}_{0.4}$	$6.9^{7.6}_{5.7}$	2.0
SAU6	$0.5^{0.7}_{0.4}$	$3.7^{4.8}_{2.9}$	2.0
BER56	$1.6^{1.7}_{1.4}$	$8.1^{8.9}_{7.4}$	4.5
BER102	$1.0^{1.5}_{0.8}$	$3.8^{4.9}_{3.0}$	2.5

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In Fig 1 we show the twenty-five selected clusters for each of the four catalogues, positioned on the face-on view of the Galaxy The spiral arms are taken from Momany et al. (2006). The large dispersion for the distances assigned to each cluster in different catalogs is clearly visible.

3. Cluster analysis

The first step in the cluster analysis is the estimation of their structural properties, i.e. center coordinates and limiting radius. Although centers and diameters are present in (some of) the catalogues, not all of these values are correct. We use our `ASteCA` package (Perren et al. 2015)[2] throughout this work to perform the structural and fundamental parameters analysis. We have applied this tool to the study of hundreds of clusters in previous articles, with excellent results (Perren et al. 2017, 2020).

The center values are obtained after applying a two-dimensional kernel density analysis (KDE) on each of the cluster's coordinates. This method assigns the center of the cluster to the point with the largest density in the frame.

4. Results

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[2] http://asteca.github.io/

5. Conclusions

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6. Conclusions

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[3] http://www.numpy.org/
[4] http://www.scipy.org/
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[6] http://matplotlib.org/

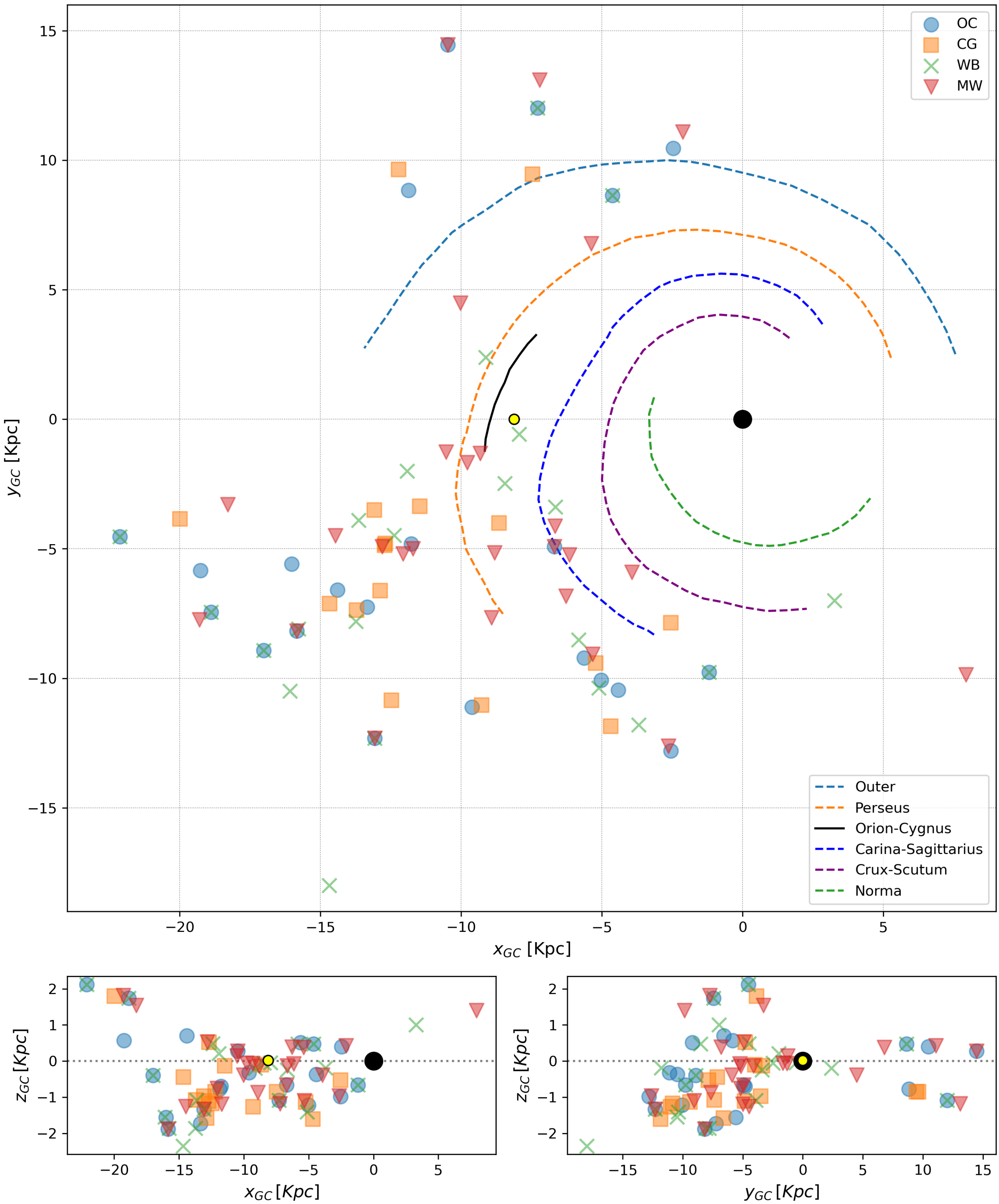

Fig. 1. Top: position of the twenty-five clusters selected from the four catalogs mentioned in the text, on a face-on view of the Milky Way. The Sun and the center of the Galaxy are marked with a yellow filled circle and a black filled circle, respectively. Bottom: edge-on views, same color and marker conventions as above.

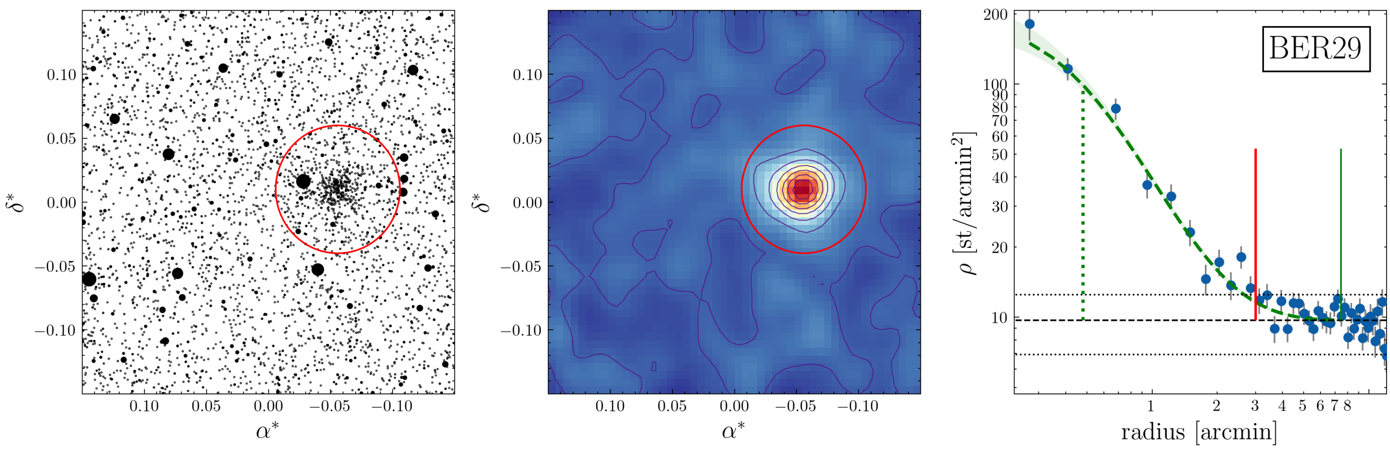

Fig. 2. xxx

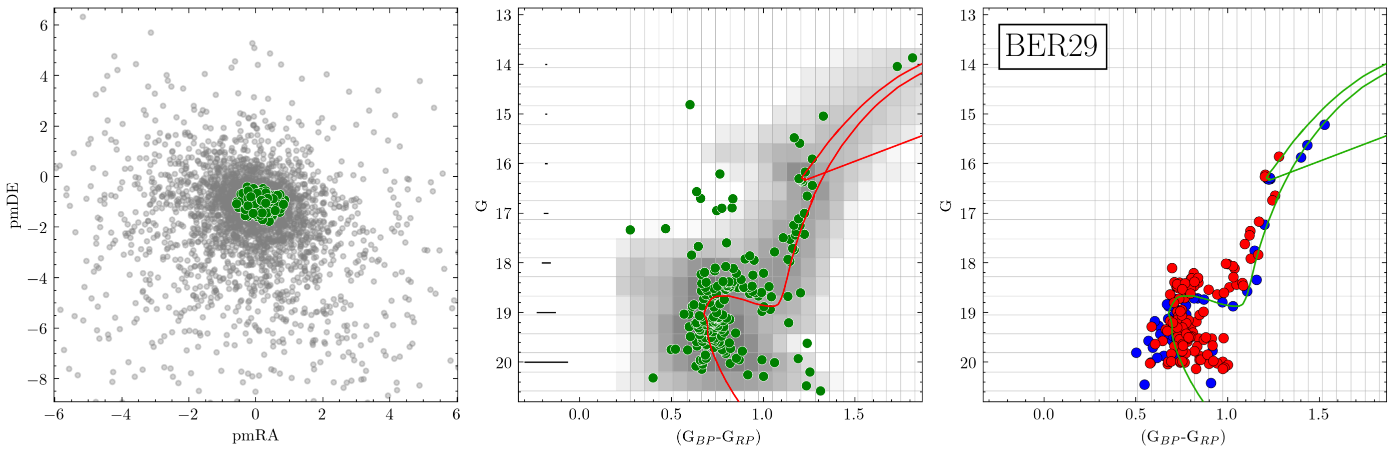

Fig. 3. xxx