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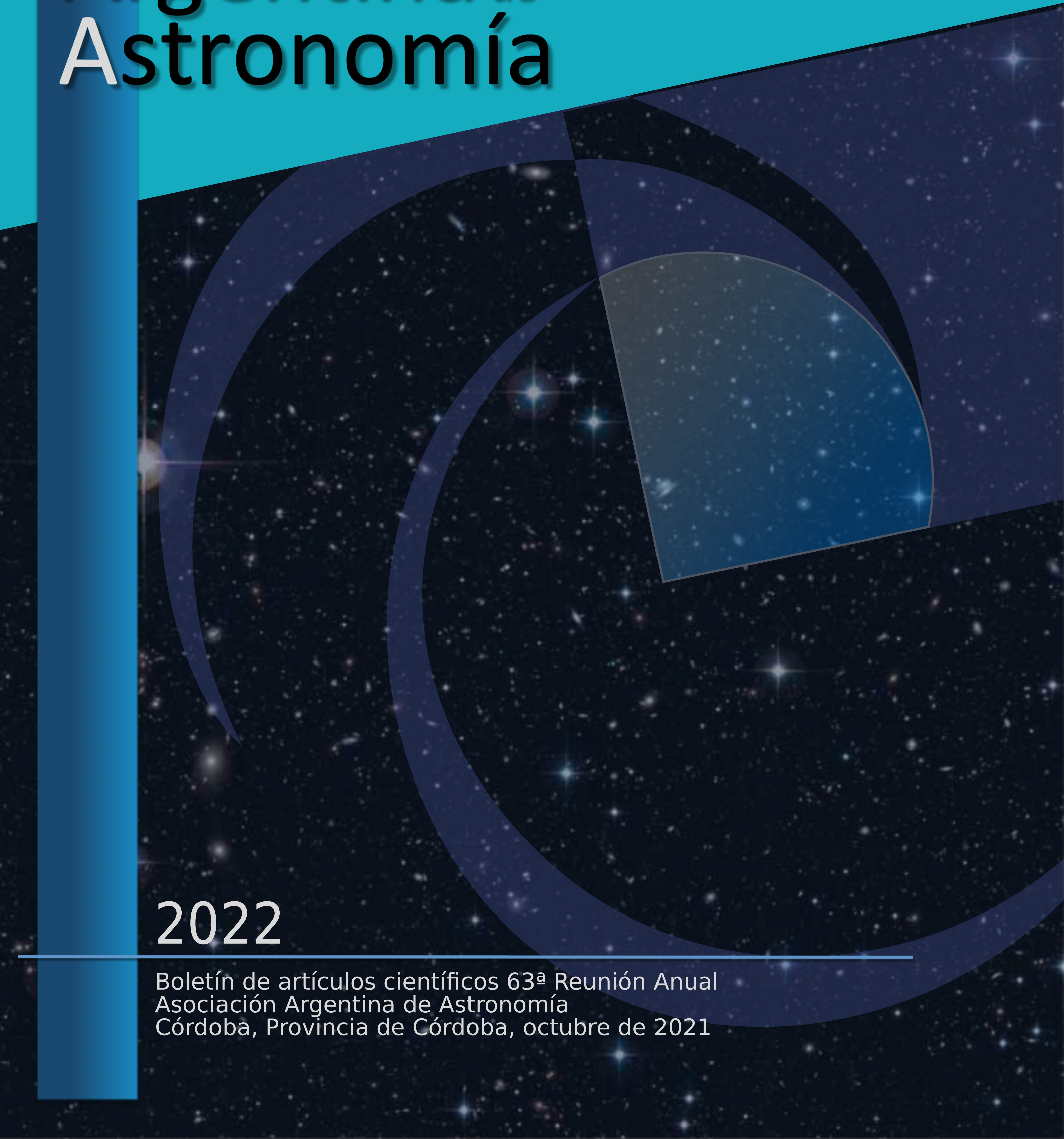

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An analysis of the twenty-five most distant open clusters

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Resumen / Presentamos un análisis de los veinticinco cúmulos abiertos con las mayores distancias catalogadas al Sol (> 9 Kpc). Los cúmulos se seleccionaron luego de comparar los cuatro catálogos publicados más grandes hasta la fecha. Los valores de distancia en estos catálogos muestran enormes diferencias entre ellos. Los datos utilizados para realizar el análisis (astrometría y fotometría) proceden de la última versión de la misión *Gaia*. Todos los cúmulos fueron procesados con dos de nuestros códigos más recientes: pyUPMASK (responsable de seleccionar los miembros más probables) y ASteCA (empleado para estimar las propiedades estructurales así como los parámetros fundamentales). Encontramos que las distancias para estos veinticinco cúmulos abiertos muestran diferencias de hasta 10 kpc. Incluso el catálogo que tiene la concordancia más cercana con las distancias obtenidas con nuestro análisis presenta diferencias de hasta 3 kpc.

Abstract / We present an analysis of the twenty-five open cluster with the largest catalogued distances to the Sun (> 9 kpc). The clusters are selected after cross-matching the four largest published catalogs to date. Distance values in these catalogs show enormous differences between them. The data used to perform the analysis (astrometry and photometry) is taken from the latest release of the *Gaia* survey. All clusters are processed with two of our most recent codes: pyUPMASK (responsible for selecting the most probable members) and ASteCA (employed to estimate the structural properties as well as the fundamental parameters). We find that the distances for these twenty-five open clusters show differences of up to 10 kpc. Even the catalog that has the closest agreement with the distances obtained after our analysis presents differences of up to 3 kpc.

Keywords / methods: statistical — galaxies: star clusters: general — open clusters and associations: general — techniques: photometric — proper motions

1. Introduction

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. We set out to estimate the differences between published open clusters' distance values across catalogs, and also using our own estimates. We cross-matched several published catalogs and selected the twenty-five most distant open clusters. We then performed a detailed analysis of their fundamental parameters, with emphasis on their distances, to determine the agreement between catalogues and our estimates. Photometric and astrometric data from the *Gaia* EDR3 (Gaia Collaboration et al., 2021) survey was employed. The data was processed with our own membership analysis code (pyUPMASK, Pera et al., 2021), and our package for automatic fundamental cluster's parameters estimation (ASteCA, Perren et al., 2015).

2. Clusters selection

We chose four catalogues to cross-match and subsequently select the most distant clusters: New Catalog of Optically Visible Open Clusters and Candidates (Dias et al., 2002, OC02), WEBDA (Netopil et al., 2012, WEBDA), Milky Way Star Clusters Catalog (Kharchenko et al., 2012, MWSC), and Cantat-Gaudin et al. (2020, CG02). Twenty-five clusters with distances larger than 9 kpc (in either of them) where selected from these four catalogs. The complete list of clusters is shown in Table 1, along with their equatorial coordinates, ages, and catalogued distances.

3. Analysis of fundamental parameters

The first step in the analysis is the estimation of the cluster's radii, which defines the cluster region where all true members are assumed to exist. We fit a two-parameter Kin profile (King, 1962) to all clusters, resulting in tidal radii spanning a range from ∼2-10 arcmin.

We then apply our pyUPMASK code to select the most likely members within this cluster region. To do this, we employ the *Gaia* EDR3 proper motion data exclusively, since parallax values are not reliable at these very large distances. The result is a selection of most

Poster contribution

Table 1: Selected open clusters with a catalogued distance ≥9000 pc, ordered by right ascension. The ages are expressed as the logarithm, and the distances are in parsec.

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

likely members, cleaned from field stars contamination.

The set of cluster members is processed with our ASteCA package to obtain the fundamental parameters of each cluster. These parameters are metallicity, age, extinction, total mass, binary fraction, and distance. They are estimated via synthetic cluster matching to the observed CMD, which is a more sophisticated and precise alternative to the widespread isochrone fitting technique (this process is explained in detail in Perren et al., 2015). The final estimates for all the parameters are shown in Table 1. The metal abundance [Fe/H] is obtained using the approximation given in the CMD service* for [M/H]. Assuming [M/H]∼[Fe/H], [Fe/H]= $\log(Z/X) - \log(Z/X)_o$, where: $(Z/X)_o = 0.0207; Y = 0.2485 + 1.78Z$.

As shown in Table 1 the analyzed clusters are quite old, with the youngest one assigned an age of $\sim$ 0.8 Gyr (but with large uncertainties). It is worth noting that only 14 out of the initial 25 clusters catalogued with distances larger than 9 kpc (∼14.8 mag) are truly beyond this limit. The binary fraction ranges from 30% up to $\sim$ 90%. The total estimated masses are found in the range [2000, 60000] $M_\odot$ with the exception of vd Bergh-Hagen 176, for which a mass of 170000 $M_\odot$ is given.

In Fig. 1 we see that all but the CG20 database show differences of up to 10 kpc between our distance estimates (using ASteCA) and those present in the four selected catalogs. Even the CG20 database, the one with the better overall match to our values, shows differences larger than 2 kpc for clusters located at a distance of $\sim$ 10 kpc from the Sun.

*CMD service: `http://stev.oapd.inaf.it/cgi-bin/cmd`

4. Conclusions

We find substantial differences in the estimated distances between our results and those catalogued, even for the Cantat-Gaudin et al. database which shows the best matches with ASteCA values out of the four databases selected. 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. These results will be further investigated in a forthcoming article.

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Table 2: Fundamental parameters estimated with ASteCA for the twenty-five analyzed clusters. Sub and supra indexes indicate the 16th and 84th percentiles, respectively.

Cluster	z	[Fe/H]	log *age*	E_{BV}	dm$_\odot$	Dist [*kpc*]	M (M$_\odot$)	b$_{fr}$
Berkeley 73	$0.0051_{0.0009}^{0.0153}$	$-0.48_{-1.24}^{0.02}$	$9.76_{9.30}^{9.93}$	$0.23_{0.10}^{0.32}$	$13.45_{13.16}^{14.13}$	$4.89_{4.28}^{6.70}$	$2.7E{+}03_{1.9E+03}^{4.8E+03}$	$0.44_{0.21}^{0.75}$
Berkeley 25	$0.0157_{0.0079}^{0.0173}$	$0.03_{-0.28}^{0.07}$	$9.78_{9.69}^{9.81}$	$0.34_{0.32}^{0.41}$	$14.29_{14.12}^{14.39}$	$7.20_{6.66}^{7.56}$	$1.4E{+}04_{9.0E+03}^{2.3E+04}$	$0.76_{0.51}^{0.93}$
Berkeley 75	$0.0084_{0.0019}^{0.0187}$	$-0.26_{-0.90}^{0.11}$	$9.78_{9.59}^{9.93}$	$0.10_{0.03}^{0.15}$	$14.50_{14.16}^{14.82}$	$7.95_{6.78}^{9.21}$	$7.0E{+}03_{2.9E+03}^{1.3E+04}$	$0.79_{0.21}^{0.96}$
Berkeley 26	$0.0215_{0.0125}^{0.0277}$	$0.18_{-0.08}^{0.30}$	$9.91_{9.72}^{10.05}$	$0.55_{0.50}^{0.58}$	$13.38_{12.98}^{13.81}$	$4.75_{3.94}^{5.77}$	$4.7E{+}03_{2.3E+03}^{8.1E+03}$	$0.76_{0.46}^{0.94}$
Berkeley 29	$0.0108_{0.0051}^{0.0174}$	$-0.14_{-0.48}^{0.08}$	$9.60_{9.55}^{9.65}$	$0.05_{0.01}^{0.11}$	$15.76_{15.64}^{15.88}$	$14.16_{13.40}^{15.03}$	$1.1E{+}04_{7.3E+03}^{2.0E+04}$	$0.60_{0.34}^{0.83}$
Tombaugh 2	$0.0068_{0.0057}^{0.0070}$	$-0.35_{-0.43}^{-0.34}$	$9.30_{9.29}^{9.31}$	$0.38_{0.38}^{0.41}$	$14.75_{14.72}^{14.76}$	$8.89_{8.80}^{8.95}$	$1.7E{+}04_{1.6E+04}^{1.9E+04}$	$0.38_{0.34}^{0.43}$
Berkeley 76	$0.0155_{0.0099}^{0.0208}$	$0.03_{-0.18}^{0.16}$	$9.25_{9.22}^{9.30}$	$0.58_{0.54}^{0.63}$	$13.70_{13.56}^{13.85}$	$5.49_{5.16}^{5.88}$	$4.6E{+}03_{2.9E+03}^{6.7E+03}$	$0.65_{0.44}^{0.80}$
FSR 1212	$0.0162_{0.0088}^{0.0250}$	$0.04_{-0.23}^{0.25}$	$9.08_{9.01}^{9.14}$	$0.65_{0.59}^{0.71}$	$15.03_{14.85}^{15.32}$	$10.15_{9.35}^{11.61}$	$4.6E{+}03_{3.3E+03}^{8.3E+03}$	$0.47_{0.30}^{0.76}$
Saurer 1	$0.0211_{0.0125}^{0.0261}$	$0.17_{-0.07}^{0.27}$	$9.81_{9.66}^{9.95}$	$0.09_{0.05}^{0.15}$	$15.48_{15.23}^{15.75}$	$12.50_{11.09}^{14.12}$	$9.7E{+}03_{4.7E+03}^{1.7E+04}$	$0.81_{0.48}^{0.95}$
Czernik 30	$0.0100_{0.0044}^{0.0216}$	$-0.18_{-0.54}^{0.18}$	$9.54_{9.44}^{9.67}$	$0.27_{0.18}^{0.36}$	$14.09_{13.93}^{14.22}$	$6.57_{6.10}^{6.98}$	$7.2E{+}03_{4.4E+03}^{1.2E+04}$	$0.78_{0.56}^{0.93}$
Arp-Madore 2	$0.0087_{0.0039}^{0.0120}$	$-0.24_{-0.60}^{-0.09}$	$9.59_{9.53}^{9.68}$	$0.62_{0.59}^{0.68}$	$15.20_{15.11}^{15.31}$	$10.97_{10.54}^{11.53}$	$8.8E{+}03_{6.7E+03}^{1.3E+04}$	$0.30_{0.16}^{0.54}$
vd BH 4	$0.0101_{0.0017}^{0.0233}$	$-0.17_{-0.96}^{0.21}$	$8.88_{8.70}^{9.25}$	$0.40_{0.32}^{0.44}$	$14.97_{14.41}^{15.51}$	$9.88_{7.64}^{12.63}$	$1.9E{+}03_{1.1E+03}^{3.5E+03}$	$0.61_{0.28}^{0.87}$
FSR 1419	$0.0243_{0.0123}^{0.0279}$	$0.24_{-0.08}^{0.30}$	$9.60_{9.52}^{9.78}$	$0.52_{0.49}^{0.59}$	$14.85_{14.57}^{15.00}$	$9.33_{8.22}^{10.01}$	$9.4E{+}03_{6.4E+03}^{1.7E+04}$	$0.56_{0.30}^{0.85}$
vd BH 37	$0.0163_{0.0043}^{0.0241}$	$0.05_{-0.55}^{0.23}$	$8.90_{8.61}^{9.68}$	$1.21_{0.80}^{1.34}$	$12.22_{10.97}^{12.86}$	$2.78_{1.56}^{3.74}$	$2.4E{+}03_{1.4E+03}^{4.1E+03}$	$0.51_{0.29}^{0.79}$
ESO 092 05	$0.0202_{0.0124}^{0.0210}$	$0.15_{-0.08}^{0.17}$	$9.74_{9.72}^{9.78}$	$0.06_{0.05}^{0.12}$	$15.57_{15.52}^{15.62}$	$13.03_{12.70}^{13.30}$	$3.3E{+}04_{2.4E+04}^{4.1E+04}$	$0.72_{0.61}^{0.82}$
ESO 092 18	$0.0178_{0.0125}^{0.0184}$	$0.09_{-0.08}^{0.10}$	$9.74_{9.73}^{9.78}$	$0.16_{0.15}^{0.19}$	$15.24_{15.21}^{15.29}$	$11.15_{11.00}^{11.41}$	$4.5E{+}04_{4.0E+04}^{5.4E+04}$	$0.57_{0.47}^{0.67}$
Saurer 3	$0.0207_{0.0078}^{0.0277}$	$0.16_{-0.29}^{0.30}$	$9.64_{9.53}^{9.88}$	$0.69_{0.66}^{0.76}$	$14.10_{13.82}^{14.49}$	$6.61_{5.81}^{7.91}$	$1.5E{+}04_{7.8E+03}^{2.1E+04}$	$0.89_{0.61}^{0.96}$
Kronberger 39	$0.0151_{0.0074}^{0.0251}$	$0.01_{-0.31}^{0.25}$	$9.46_{9.34}^{9.69}$	$0.75_{0.67}^{0.84}$	$15.54_{15.20}^{15.80}$	$12.84_{10.98}^{14.44}$	$1.2E{+}04_{5.9E+03}^{2.5E+04}$	$0.72_{0.36}^{0.93}$
ESO 093 08	$0.0073_{0.0023}^{0.0182}$	$-0.32_{-0.82}^{0.10}$	$9.93_{9.54}^{10.05}$	$0.67_{0.58}^{0.79}$	$15.61_{15.37}^{15.83}$	$13.26_{11.86}^{14.66}$	$3.4E{+}04_{1.5E+04}^{6.7E+04}$	$0.66_{0.31}^{0.89}$
vd BH 144	$0.0034_{0.0031}^{0.0057}$	$-0.65_{-0.69}^{-0.43}$	$9.02_{8.93}^{9.10}$	$0.82_{0.78}^{0.88}$	$14.90_{14.83}^{15.06}$	$9.55_{9.23}^{10.26}$	$6.6E{+}03_{5.7E+03}^{8.0E+03}$	$0.36_{0.27}^{0.45}$
vd BH 176	$0.0256_{0.0122}^{0.0272}$	$0.26_{-0.08}^{0.29}$	$9.71_{9.68}^{9.77}$	$0.44_{0.42}^{0.50}$	$16.48_{16.42}^{16.53}$	$19.78_{19.20}^{20.22}$	$1.7E{+}05_{1.4E+05}^{1.9E+05}$	$0.46_{0.29}^{0.60}$
Kronberger 31	$0.0155_{0.0068}^{0.0243}$	$0.02_{-0.35}^{0.23}$	$8.99_{8.91}^{9.07}$	$1.24_{1.18}^{1.32}$	$14.59_{14.31}^{14.80}$	$8.27_{7.27}^{9.12}$	$8.2E{+}03_{5.5E+03}^{1.3E+04}$	$0.78_{0.61}^{0.92}$
Saurer 6	$0.0149_{0.0065}^{0.0248}$	$0.01_{-0.37}^{0.24}$	$9.15_{9.05}^{9.53}$	$0.92_{0.81}^{1.03}$	$14.85_{14.11}^{15.15}$	$9.34_{6.64}^{10.72}$	$4.9E{+}03_{3.3E+03}^{7.5E+03}$	$0.52_{0.33}^{0.72}$
Berkeley 56	$0.0181_{0.0065}^{0.0265}$	$0.10_{-0.37}^{0.28}$	$9.75_{9.72}^{9.76}$	$0.42_{0.38}^{0.51}$	$15.21_{15.16}^{15.25}$	$11.00_{10.79}^{11.21}$	$5.9E{+}04_{4.8E+04}^{7.1E+04}$	$0.66_{0.57}^{0.74}$
Berkeley 102	$0.0111_{0.0059}^{0.0228}$	$-0.13_{-0.41}^{0.20}$	$9.69_{9.57}^{9.82}$	$0.44_{0.37}^{0.51}$	$14.43_{14.19}^{14.61}$	$7.68_{6.89}^{8.37}$	$6.2E{+}03_{4.1E+03}^{9.4E+03}$	$0.59_{0.38}^{0.78}$

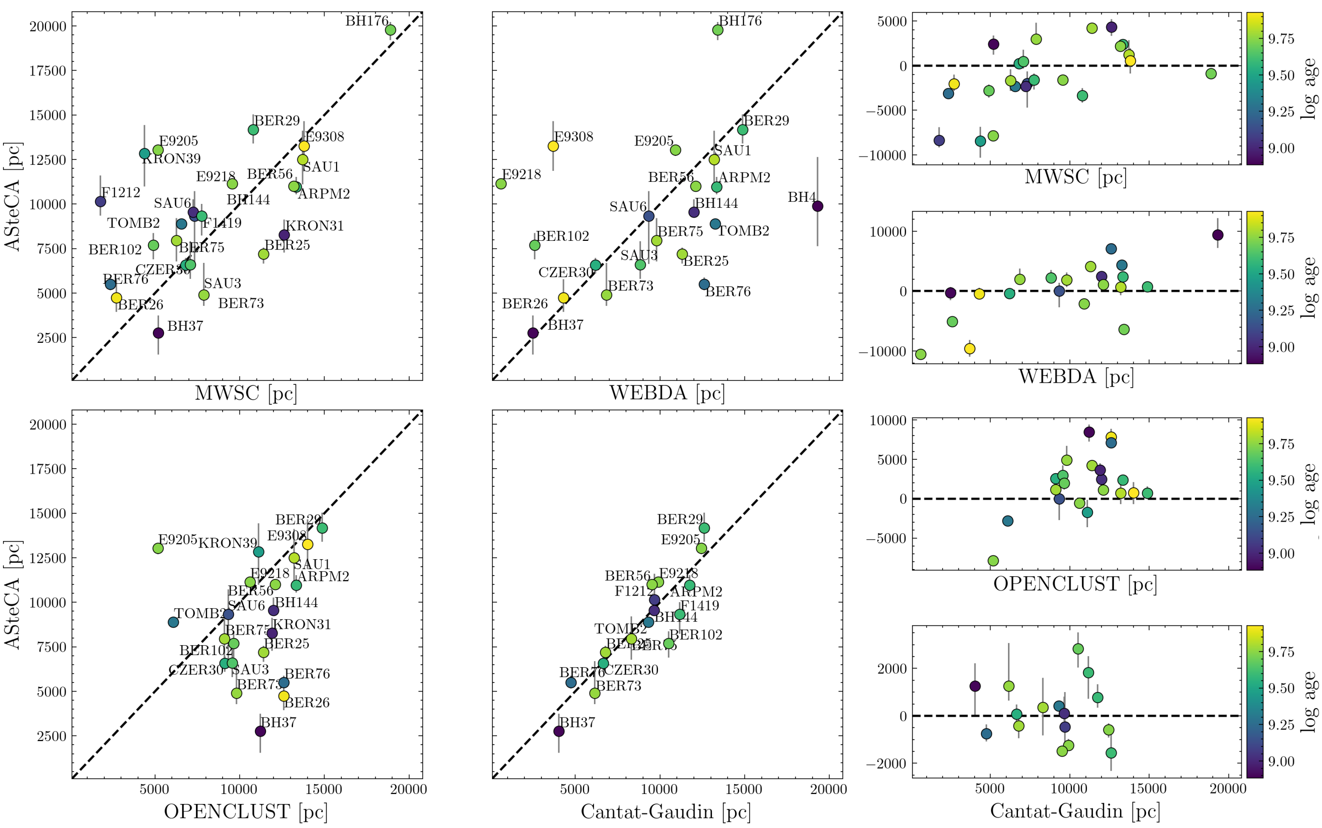

Figure 1: ASteCA versus database distances. The plots to the right stacked vertically are the ASteCA distances versus the differences in the sense (ASteCA - database). Clusters are colored according to the log *age* assigned by ASteCA.