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Impossible Survivors: New Star Cluster Candidates in the Galactic Bulge

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We have extended our search for globular cluster (GC) candidates into the central regions of the Milky Way (MW), using the VISTA Variables in the Via Lactea survey (VVV, Minniti et al. 2010), and its extension the VVVX survey, supplemented with data from 2MASS (Skrutskie et al. 2006) and Gaia DR2 (The Gaia Collaboration 2018).

While we follow the selection procedures described by Minniti et al. (2017abc, 2019a), we have also included in this search smaller (arcminute size) objects. This is justified because all the major classical GCs have already been discovered in the bulge, although in this region we also expect to find GCs in advanced stages of destruction. Dynamical friction drags the GCs into the inner regions of the MW with higher field stellar densities, where their demise is accelerated by the tidal action (Tremaine & Weinberg 1994, Gnedin & Ostriker 1997, Gieles & Baumgardt 2008). Simulations suggest that objects in advanced stages of disruption might exhibit compact cores surrounded by extended tails or envelopes (e.g. Habibi et al. 2013, Hosek et al. 2015). The high field stellar density combined with the variable extinction prevent us from reliably detecting the extended features. Our main premise, however, is that it should be possible to detect the remnant compact cores as conspicuous overdensities on top of the bulge background.

Table 1 lists 194 new star cluster candidates, including their IDs, Galactic coordinates, equatorial coordinates, and K_s-band extinctions taken from Schlafly & Finkbeiner (2011). The comments in the last column give the number of known RR Lyrae (RRL), Type 2 Cepheids (T2C), classical Cepheids (CCep), and Mira (Mir) variable stars, planetary nebulae (PN), and X-ray point sources (XRS) found using Aladdin/Simbad/CDS within 3' from the cluster centres. Previously known candidate clusters in the vicinity (matching positions within 5') are also included.

The field extinctions are high as most of the candidates are located at low Galactic latitudes. In particular, there are 13 candidates with $A_K > 5.0$ mag (equivalent to $A_V > 45$ mag). If confirmed, these would be the GCs with the highest extinctions known so far. Interestingly, there are 16 candidates that contain a PN within 3' from the cluster centres. While some may be chance alignments, the identification of new GC PN is important since few of these objects are known, so follow-up radial velocities are needed for confirmation (Minniti et al. 2019b). Also, there are 48 GC candidates with 5 or more RRL within 3'. Some of these may be field RRL as the number density of bulge RRL is high. It is important to establish the potential cluster membership for these RRL, because those variables are excellent distance and reddening indicators. There are also 36 candidates with one or more XRS within 3'. These are interesting targets to follow with the eRosita satellite (Predehl et al. 2020).

A caveat is that the individual object classifications are challenging, since the objects that are not real GCs (or their debris) could be foreground open clusters, occasional holes in the interstellar clouds, or mere asterisms. The GC

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candidates need to be confirmed with deeper photometric, astrometric, and spectroscopic follow-up observations, as stressed by Minniti et al. (2017abc) and Palma et al. (2019).

Table 1. New VVV Star Cluster Candidates in the Galactic Bulge

ID	GL	GB	RA(J2000)	DEC(J2000)	A_{Ks}	Comments
Minni136	8.117	9.082	17 30 42.7	-17 16 06	0.113	1XRS
Minni137	9.284	5.686	17 45 23.9	-18 03 45	0.186	
Minni138	9.801	9.709	17 32 10.1	-15 31 41	0.119	
Minni139	6.136	5.401	17 39 30.8	-20 53 11	0.213	1RRL
Minni140	4.179	6.194	17 32 10.1	-22 06 43	0.311	1RRL, 1XRS
Minni141	8.132	8.564	17 32 34.8	-17 31 55	0.112	1RRL
Minni142	3.840	7.420	17 26 56.5	-21 43 43	0.370	
Minni143	7.030	9.910	17 25 21.8	-17 43 41	0.100	1RRL
Minni144	4.170	-11.200	18 40 09.5	-30 34 26	0.045	3RRL
Minni145	7.270	-13.000	18 53 28.3	-28 33 44	0.056	5RRL
Minni146	3.970	-14.110	18 52 12.1	-31 56 45	0.039	3RRL
Minni147	4.000	-11.700	18 41 56.5	-30 56 07	0.038	2RRL
Minni148	5.360	-13.380	18 51 36.2	-30 24 58	0.043	2RRL
Minni149	359.9672	2.0568	17 37 35.9	-27 52 40	0.478	1RRL
Minni150	359.9804	2.3584	17 36 28.8	-27 42 17	0.503	2RRL
Minni151	0.0251	2.4765	17 36 08.3	-27 36 13	0.468	4RRL
Minni152	0.2347	2.3670	17 37 03.7	-27 29 09	0.492	3RRL
Minni153	0.2064	2.2311	17 37 30.7	-27 34 57	0.502	4RRL, 1T2C
Minni154	0.3027	2.1242	17 38 09.1	-27 33 30	0.462	6RRL
Minni155	0.1494	2.0381	17 38 06.6	-27 44 02	0.447	1RRL, 1PN
Minni156	0.2422	1.9906	17 38 30.9	-27 40 51	0.448	5RRL
Minni157	0.2053	1.7986	17 39 09.7	-27 48 51	0.520	8RRL, 1XRS
Minni158	0.1941	1.2763	17 41 08.3	-28 06 03	0.555	3RRL
Minni159	0.1990	1.2087	17 41 24.7	-28 07 57	0.545	
Minni160	0.1130	1.1174	17 41 33.4	-28 15 13	0.590	5RRL, 1XRS
Minni161	0.2005	0.1169	17 45 38.5	-28 42 15	20.282	1Mir, >20XRS
Minni162	0.2674	-0.5937	17 48 34.5	-29 00 55	2.761	
Minni163	0.2647	-0.7200	17 49 03.9	-29 04 57	2.213	
Minni164	0.2234	-0.7836	17 49 13.0	-29 09 03	2.010	
Minni165	0.2250	-0.8454	17 49 27.8	-29 10 52	1.669	
Minni166	0.1835	-0.9069	17 49 36.4	-29 14 54	1.078	1Mir, 1T2C
Minni167	0.1418	-0.9254	17 49 34.9	-29 17 37	0.991	1RRL, 1T2C, 4Mir, 1XRS
Minni168	0.1429	-1.0080	17 49 54.6	-29 20 07	0.767	6RRL 8Mir
Minni169	0.1142	-1.3509	17 51 11.7	-29 32 07	0.373	11RRL, 2Mir, 6XRS, 1PN
Minni170	0.2779	-1.3628	17 51 37.5	-29 24 03	0.392	8RRL, 5Mir
Minni171	0.1806	-1.6679	17 52 36.3	-29 38 23	0.326	6RRL, 4Mir, 1XRS
Minni172	0.4450	-2.1804	17 55 15.3	-29 40 16	0.308	7RRL , 4Mir
Minni173	0.5189	-1.5824	17 53 03.3	-29 18 18	0.375	3RRL, 2Mir, 1T2C, 1XRS
Minni174	0.3925	-1.1273	17 50 57.9	-29 10 55	0.566	9RRL, 1Mir
Minni175	0.5070	-1.0426	17 50 54.0	-29 02 25	0.652	4RRL
Minni176	0.5671	-0.0916	17 47 19.3	-28 29 57	39.619	>20XRS
Minni177	0.4436	0.5252	17 44 38.0	-28 17 01	1.716	
Minni178	0.5028	0.5552	17 44 39.5	-28 13 03	1.725	
Minni179	0.5830	0.8090	17 43 52.1	-28 00 59	1.438	
Minni180	0.4564	1.0148	17 42 46.4	-28 00 58	0.653	2RRL – DutraBica22 at 3

Table 1. (cont.)

D	GL	GB	RA(J2000)	DEC(J2000)	A_{Ks}	Comments
Minni181	0.6177	1.5616	17 41 03.4	-27 35 26	0.530	5RRL, 1XRS
Minni182	0.5005	1.9308	17 39 21.9	-27 29 39	0.428	4RRL, 1PN, 1XRS
Minni183	0.6007	2.3301	17 38 05.0	-27 11 48	0.437	4RRL
Minni184	0.7282	1.6484	17 40 59.3	-27 27 03	0.559	4RRL
Minni185	0.7622	1.5048	17 41 37.1	-27 29 53	0.573	5RRL, 1T2C
Minni186	0.8907	1.4230	17 42 14.3	-27 25 55	0.673	9RRL, 1XRS
Minni187	0.8560	1.2815	17 42 41.9	-27 32 09	0.592	10RRL, 1PN, 1XRS – DutraBica19 at 3.5 Minni46 at 4.6
Minni188	0.7281	1.0675	17 43 13.0	-27 45 26	0.866	13RRL – Minni60 at 3.2
Minni189	0.8595	1.0597	17 43 33.5	-27 38 58	0.755	10RRL – Minni60 at 5
Minni190	0.7838	0.9205	17 43 54.8	-27 47 13	1.462	1RRL, 1PN
Minni191	0.7709	0.8777	17 44 02.9	-27 49 13	1.638	
Minni192	0.8796	0.9206	17 44 08.4	-27 42 19	1.338	1PN – DutraBica23 at 2.5
Minni193	0.8733	0.7778	17 44 40.5	-27 47 07	2.129	4XRS
Minni194	0.7895	0.7811	17 44 27.9	-27 51 18	2.162	
Minni195	0.7437	0.1915	17 46 38.2	-28 12 05	9.390	8XRS
Minni196	0.8971	-0.4788	17 49 36.3	-28 24 59	5.742	
Minni197	0.7799	-0.5707	17 49 41.4	-28 33 51	3.109	
Minni198	0.9205	-1.4585	17 53 30.0	-28 53 46	0.573	8RRL, 1PN, 1Mir
Minni199	0.9549	-1.8668	17 55 11.4	-29 04 27	0.358	5RRL, 1XRS – DutraBica24 at 5
Minni200	0.8217	-1.9388	17 55 10.0	-29 13 27	0.395	4RRL, 3Mir
Minni201	1.1010	-2.4492	17 57 50.0	-29 14 19	1.628	4RRL, 2Mir
Minni202	1.1590	-1.9183	17 55 51.8	-28 55 21	0.376	9RRL
Minni203	1.1756	-0.8269	17 51 36.7	-28 21 19	1.171	14RRL, 1XRS, 1CCep
Minni204	1.1694	-0.7232	17 51 11.6	-28 18 28	1.599	4RRL, 1T2C
Minni205	1.1641	0.0810	17 48 03.1	-27 53 56	17.276	
Minni206	1.3170	0.7694	17 45 45.2	-27 24 40	2.290	1RRL
Minni207	1.2176	1.3984	17 43 06.3	-27 10 01	0.664	3RRL
Minni208	1.2221	1.9224	17 41 07.0	-26 53 13	0.825	6RRL
Minni209	1.2400	2.4684	17 39 05.1	-26 34 57	0.517	4RRL
Minni210	1.5069	2.2189	17 40 39.8	-26 29 19	0.615	4RRL
Minni211	1.4505	2.1656	17 40 43.9	-26 33 53	0.667	7RRL
Minni212	1.5520	1.7467	17 42 33.9	-26 41 58	0.709	4RRL
Minni213	1.5151	1.2229	17 44 28.6	-27 00 20	0.802	7RRL
Minni214	1.4294	1.0047	17 45 06.7	-27 11 33	1.249	2RRL
Minni215	1.4403	0.7984	17 45 55.8	-27 17 27	1.913	1RRL
Minni216	1.4123	0.6908	17 46 16.7	-27 22 15	2.238	
Minni217	1.5381	-0.7800	17 52 16.1	-28 01 10	3.419	3RRL, 1PN
Minni218	1.4211	-1.2764	17 53 56.4	-28 22 21	0.701	10RRL, 4XRS – Minni34 at 4.5
Minni219	1.4292	-1.8687	17 56 17.2	-28 39 51	0.377	6RRL, 2Mir, 2XRS
Minni220	1.7254	-2.4885	17 59 24.5	-28 43 02	0.263	4RRL , 2Mir
Minni221	1.7392	-1.6206	17 56 01.1	-28 16 18	0.673	6RRL, 1PN, 2XRS
Minni222	1.6612	-1.5327	17 55 29.7	-28 17 41	0.685	1PN
Minni223	1.7345	0.1273	17 49 12.1	-27 23 11	10.058	1XRS
Minni224	1.7403	0.2812	17 48 37.3	-27 18 08	6.602	
Minni225	1.7826	0.7667	17 46 51.1	-27 00 53	1.312	3RRL, 1PN, 1T2C
Minni226	1.7797	1.0282	17 45 50.5	-26 52 53	1.133	4RRL
Minni227	1.7740	1.2866	17 44 50.4	-26 45 06	0.853	4RRL

Table 1. (cont.)

D	GL	GB	RA(J2000)	DEC(J2000)	A_{Ks}	Comments
Minni228	1.7722	1.3192	17 44 42.7	-26 44 10	0.811	4RRL
Minni229	1.7066	1.6863	17 43 09.5	-26 35 59	0.662	5RRL, 1PN, 1T2C
Minni230	1.6951	1.8105	17 42 39.5	-26 32 40	0.585	6RRL – Minni44 at 4
Minni231	1.7392	1.9204	17 42 20.6	-26 26 57	0.559	2RRL
Minni232	1.8604	1.9483	17 42 31.4	-26 19 53	0.531	2RRL, 2XRS
Minni233	1.7319	2.0649	17 41 46.7	-26 22 45	0.585	7RRL
Minni234	1.8253	2.1383	17 41 43.2	-26 15 40	0.593	3RRL, 1PN
Minni235	1.6837	2.4006	17 41 23.2	-26 22 53	0.707	4RRL
Minni236	1.8247	2.5992	17 39 58.5	-26 01 05	0.532	4RRL
Minni237	1.6635	2.5993	17 39 35.6	-26 09 16	0.463	8RRL
Minni238	1.8722	2.6746	17 39 48.1	-25 56 16	0.568	5RRL
Minni239	1.8756	2.5834	17 40 09.3	-25 59 00	0.579	3RRL
Minni240	2.0211	2.4043	17 41 10.4	-25 57 16	0.574	3RRL
Minni241	359.8421	0.8515	17 41 56.0	-28 37 27	0.841	
Minni242	1.9712	1.6485	17 43 55.3	-26 23 40	0.650	7RRL
Minni243	1.9465	1.2271	17 45 28.2	-26 38 08	1.128	2RRL – DutraBica33 at 4'
Minni244	1.9019	1.1813	17 45 32.5	-26 41 51	1.255	5RRL, 2XRS – DutraBica33 at 1'
Minni245	1.9798	1.0196	17 46 20.5	-26 42 54	0.991	3RRL
Minni246	2.0419	0.7040	17 47 41.7	-26 49 32	2.057	2RRL, 1PN
Minni247	1.9235	0.4547	17 48 22.7	-27 03 21	3.138	
Minni248	2.0365	0.3657	17 48 58.9	-27 00 17	3.698	
Minni249	1.9632	0.1737	17 49 33.1	-27 09 59	8.220	
Minni250	2.0334	0.1041	17 49 58.9	-27 08 31	8.273	1CCep
Minni251	1.9529	-0.5072	17 52 09.7	-27 31 26	3.758	
Minni252	2.0372	-0.7990	17 53 29.4	-27 35 58	2.472	
Minni253	1.9657	-1.4074	17 55 42.0	-27 58 07	1.104	4RRL
Minni254	2.0209	-1.5024	17 56 11.8	-27 58 08	0.954	5RRL
Minni255	2.0721	-1.5806	17 56 37.2	-27 57 50	0.883	8RRL, 1XRS
Minni256	2.0722	-2.3339	17 59 34.9	-28 20 23	0.321	5RRL
Minni257	2.0745	-2.3885	17 59 48.1	-28 21 53	0.298	8RRL
Minni258	2.1934	-1.9458	17 58 19.6	-28 02 30	0.490	3RRL, 1Mir
Minni259	2.1451	-1.7122	17 57 18.0	-27 58 00	0.689	1RRL, 1Mir, 1XRS
Minni260	2.1526	-1.4782	17 56 24.1	-27 50 34	1.213	8RRL
Minni261	2.2232	-1.1497	17 55 16.8	-27 36 59	1.467	6RRL, 2XRS
Minni262	2.1861	-0.9872	17 54 33.7	-27 33 59	1.752	1RRL
Minni263	2.1842	-0.9916	17 54 34.5	-27 34 13	1.728	1RRL
Minni264	2.2188	-0.6367	17 53 16.5	-27 21 39	3.734	– Czernik 37 at 1'
Minni265	2.1790	-0.2565	17 51 42.6	-27 12 05	9.334	
Minni266	2.2706	-0.0982	17 51 18.5	-27 02 31	10.710	
Minni267	2.3888	0.2129	17 50 22.9	-26 46 52	7.604	
Minni268	2.2914	0.6199	17 48 35.6	-26 39 19	2.181	2RRL
Minni269	2.3512	0.8539	17 47 50.1	-26 29 00	1.401	
Minni270	2.4692	0.9323	17 47 48.5	-26 20 30	1.287	2RRL, 1XRS
Minni271	2.3773	1.7651	17 44 25.5	-25 59 15	0.596	3RRL, 1XRS
Minni272	2.3444	2.0477	17 43 16.6	-25 52 03	0.534	4RRL
Minni273	0.8774	-3.0501	17 59 43.0	-29 43 53	0.298	3RRL
Minni274	0.9886	-2.7376	17 58 43.0	-29 28 46	0.329	5RRL, 1Mir

Table 1. (cont.)

D	GL	GB	RA(J2000)	DEC(J2000)	A_{Ks}	Comments
Minni275	0.9291	-2.3481	17 57 02.3	-29 20 13	0.306	4RRL
Minni276	359.8276	0.4352	17 43 30.8	-28 51 20	2.072	
Minni277	359.9289	1.7277	17 38 46.0	-28 05 09	0.404	3RRL, 1PN
Minni278	359.9981	1.6496	17 39 14.0	-28 04 08	0.394	5RRL, 2XRS
Minni279	8.4798	2.6276	17 54 49.0	-20 18 37	0.488	
Minni280	10.5566	3.6689	17 55 25.0	-17 59 39	0.342	2RRL
Minni281	358.2157	0.7828	17 38 14.2	-30 02 18	2.145	
Minni282	358.2857	1.4195	17 35 56.0	-29 38 15	0.777	3RRL, 1CCep
Minni283	358.5686	0.5707	17 39 56.0	-29 51 11	2.104	
Minni284	358.5344	0.1869	17 41 21.2	-30 05 08	5.413	7XRS, 1CCep
Minni285	358.8677	-1.4340	17 48 34.1	-30 38 51	0.889	5RRL, 1XRS, 1Mir
Minni286	358.8176	-1.2199	17 47 35.8	-30 34 48	1.062	
Minni287	358.8274	0.4351	17 41 05.8	-29 42 20	3.190	
Minni288	358.7565	1.7103	17 35 58.4	-29 05 04	0.604	4RRL, 2XRS
Minni289	358.9266	-1.3597	17 48 24.8	-30 33 32	0.890	3RRL
Minni290	359.4559	2.1260	17 36 05.5	-28 16 18	0.573	
Minni291	359.5476	1.9847	17 36 51.3	-28 16 13	0.573	2RRL – Camargo1105 at 4.5
Minni292	359.4578	1.6684	17 37 51.1	-28 30 56	0.518	5RRL, 1XRS
Minni293	359.5779	1.5074	17 38 45.8	-28 30 00	0.477	5RRL, 4XRS – VVV CL127 at 1
Minni294	359.5303	1.2679	17 39 34.0	-28 40 01	0.802	3RRL, repeated Minni297
Minni295	359.6619	1.1775	17 40 14.3	-28 36 16	0.794	1XRS
Minni296	359.5984	0.9366	17 41 01.0	-28 47 10	0.900	1PN, 1XRS, 1T2C – Minni02 at 3.6
Minni297	359.5306	1.2693	17 39 34.0	-28 40 01	0.802	3RRL, repeated Minni294
Minni298	359.6182	0.7728	17 41 41.9	-28 51 21	1.123	
Minni299	359.6290	0.7366	17 41 51.9	-28 51 57	1.158	
Minni300	359.6200	-1.6528	17 51 13.7	-30 06 51	0.393	8RRL, 2Mir – NGC6451 at 1
Minni301	359.7944	-2.5548	17 55 14.3	-30 25 17	0.416	2RRL, 1Mir
Minni302	359.9007	-1.5305	17 51 24.2	-29 48 38	0.354	11RRL, 3Mir, 1XRS – Minni59 at 1.5
Minni303	359.9184	-1.4190	17 51 00.2	-29 44 18	0.483	13RRL, 2Mir, 1XRS
Minni304	359.9444	-1.1979	17 50 11.4	-29 36 10	0.415	10RRL, 6Mir
Minni305	359.8979	-1.1229	17 49 47.1	-29 36 16	0.509	8RRL, 4Mir, 1XRS
Minni306	359.9344	-1.0933	17 49 45.3	-29 33 28	0.487	11RRL, 6Mir
Minni307	359.8981	-0.9519	17 49 06.6	-29 30 59	0.913	1RRL – VVV CL149 at 4.5
Minni308	0.0551	1.9718	17 38 08.2	-27 50 56	0.460	1RRL
Minni309	8.2707	-7.0796	18 31 23.0	-25 07 58	0.108	1Mir
Minni310	5.4515	-9.1751	18 34 15.0	-28 33 49	0.079	2RRL
Minni311	5.2749	-9.3210	18 34 30.0	-28 47 03	0.081	
Minni312	5.2184	-9.3805	18 34 38.0	-28 51 37	0.083	
Minni313	10.5925	-9.5384	18 45 33.0	-24 09 08	0.111	
Minni314	4.1960	2.5361	17 45 42.0	-24 02 04	0.409	1RRL, 1Mir
Minni315	6.1649	3.6340	17 46 03.0	-21 47 03	0.376	2RRL
Minni316	9.3194	4.9597	17 48 06.0	-18 24 17	0.268	1RRL
Minni317	5.8982	2.7664	17 48 40.0	-22 27 35	0.350	2RRL, 2Mir
Minni318	3.8374	1.2882	17 49 35.0	-24 59 10	1.352	
Minni319	4.1615	1.4645	17 49 39.0	-24 37 03	1.000	4RRL
Minni320	4.4588	1.8371	17 48 55.0	-24 10 16	0.722	1RRL
Minni321	8.3033	4.1598	17 48 49.0	-19 41 03	0.293	

Table 1. (cont.)

D	GL	GB	RA(J2000)	DEC(J2000)	A_{Ks}	Comments
Minni322	7.5733	3.7757	17 48 38.0	-20 30 23	0.341	
Minni323	3.9861	1.9792	17 47 18.8	-24 30 09	0.860	1RRL
Minni324	5.782	-11.940	18 46 19.2	-29 27 00	0.053	2RRL
Minni325	4.117	-14.501	18 54 09.6	-31 58 12	0.036	
Minni326	5.764	-13.091	18 51 07.2	-29 56 24	0.049	3RRL
Minni327	6.570	-15.019	19 00 43.2	-29 59 24	0.044	
Minni328	5.265	-12.399	18 47 16.8	-30 06 00	0.053	2RRL
Minni329	5.087	-11.822	18 44 31.2	-30 01 12	0.040	3RRL
Minni330	6.122	-14.008	18 55 38.4	-29 59 24	0.043	2RRL

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