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Evidence of Galaxy Expansion from Globular Clusters

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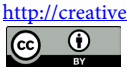

Abstract

In modern astrophysics, it is believed that galaxies are not expanding. The authors of the article set out to investigate the motion of Globular Clusters (GC) of the Milky Way relative to the plane and center of the Galaxy. The study yielded the following results: 1. The average velocity of the GC relative to the Galactic plane for the northern region of the Galaxy has a positive value of approximately 30.36 ± 15.29 km/s ($N = 42$) for the range $0^\circ < b < 13^\circ$. 2. For the southern region, the following result was obtained: the average velocity of GC movement relative to the plane in the southern direction is -17.83 ±13.54 km/s ($N = 50$) for the range $-13^\circ < b < 0^\circ$. 3. The average velocity of the GC relative to the Galactic center for the range 0 to 12 kpc is 31.70 ± 14.74 km/s ($N = 119$). Thus, we can state that the Galaxy is possibly expanding, at least in its central part. This seems unlikely as it does not agree with the current theory, so it can be considered a preliminary result requiring further study. However, if we accept the idea of the expansion of the Galaxy, we can answer a number of questions. In particular, we can explain the existence of massive galaxies discovered by the James Webb Space Telescope (JWST), whose age is estimated to be less than 1 billion years.

Keywords

Globular Clusters, Galactic Center, Galaxy Expansion

1. Introduction

As galaxies are not considered to be expanding, there are almost no papers devoted to this topic in the literature. A rare exception is the paper [1]. In this paper,

they explore the truncations in two nearby ($D \sim 15$ Mpc) Milky Way-like galaxies: NGC 4565 and NGC 5907. The vertical extent of the truncation, as well as the colour properties in the mid-plane beyond the truncation, are consistent with an upper limit for the current growth speed for the discs of the galaxies of 0.6 - 1 kpc Gyr -1, which corresponds to a speed of approximately 500 - 1000 m/s.

Our goal was to determine the expansion of the Galaxy by studying the motion of well-studied globular clusters.

The new Gaia Mission EDR3 and ED3 data represent improved parameters of the photometric and astrometric catalogs compared to previous versions. In particular, the inaccuracies in parallaxes ω and proper motions μ were reduced on average by a factor of two, and systematic inaccuracies were reduced even more. Already DR2 has made it possible to calculate the average parallaxes ([2] [3]) and proper motions of almost all GC ([4]-[6]) of the Milky Way. Since GC stars have similar kinematic properties and parallaxes, [7] used these data sets (up to tens of thousands of stars in the richest clusters) to determine whether these stars belong to the GC and calculate their general parameters. Thus, a catalog of 164 GC with the necessary parameters was created, which we used to study the velocities of these GC relative to the plane $V\uparrow$ and $V\downarrow$ (north and south regions) and center (VR) of the Milky Way Galaxy. First, we calculated the velocities of movement of all GC in the orthogonal direction relative to the plane for the northern and southern regions of the Galaxy. Further, in Section 2.1 we calculated the average GC movement velocities depending on the Galactic latitude b, and in Section 2.2, separately, on the distance of the GC to the Galactic plane. **Figure 1** and **Figure 2** show the dependence of GC velocities on galactic latitude for the northern and southern regions of the Galaxy. **Table 1** and **Table 2** summarize the main findings of the study.

2. Method

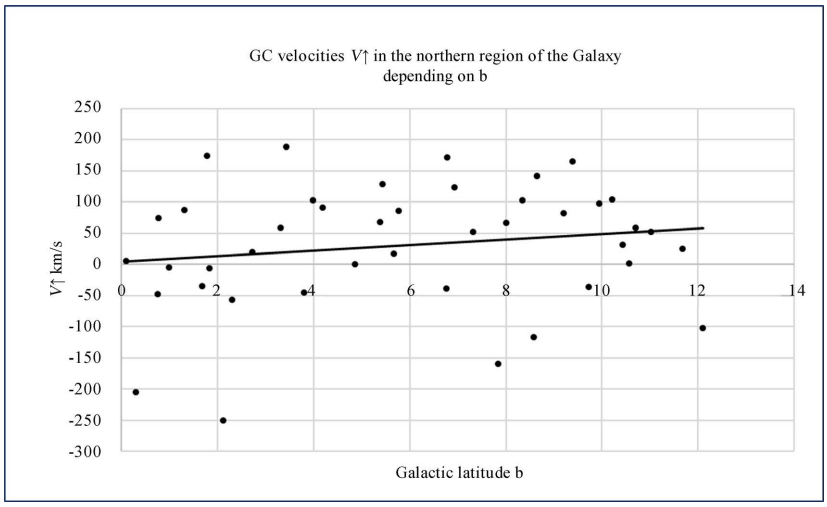

Figure 1. GC velocities V↑ in the northern region of the Galaxy depending on coordinate b. As can be seen from the figure, most GCs have a positive velocity, *i.e.* moving away from the galactic plane.

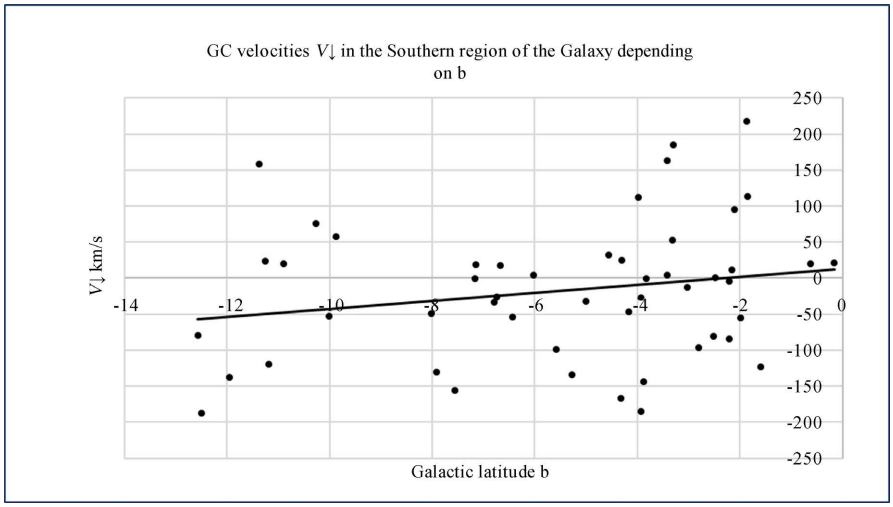

Figure 2. GC velocities V↓ in the southern region of the Galaxy depending on coordinate b. Most GCs have a negative velocity, *i.e.* moving away from the galactic plane.

Table 1. The sample for $-13^{\circ} < b < 13^{\circ}$ consists of 92 GCs.

Name	*RA*	*DEC*	R_{sun} kpc	*b* deg	μl [mas yr-1]	μb [mas yr-1]	$V\uparrow$, $V\downarrow$ km/s
ESO_452-SC11	249.854167	−28.399167	7.39	12.10	−5.8677450	−3.0835660	−102.18
Rup_106	189.667500	−51.150278	20.71	11.67	−1.2716863	0.3370817	24.67
NGC_6287	256.288904	−22.708005	7.93	11.02	−4.4497451	2.9439506	52.34
NGC_6333	259.799086	−18.516257	8.3	10.71	−3.8819845	0.0400754	59.27
NGC_5286	206.611710	−51.374249	11.1	10.57	0.1481820	−0.1964969	1.27
NGC_6535	270.960449	−0.297639	6.36	10.44	−4.5564066	2.3670137	31.31
NGC_6356	260.895804	−17.813027	15.66	10.22	−4.9125405	1.3039966	103.88
NGC_6284	256.120114	−24.764799	14.21	9.94	−3.5101230	1.4025257	98.06
NGC_6342	260.291573	−19.587659	8.01	9.73	−7.5343118	−1.4921814	−36.33
NGC_6273	255.657486	−26.267971	8.34	9.38	−0.6054084	3.6079414	164.55
Ter_3	247.162483	−35.339829	7.64	9.20	−5.0790522	2.8935819	81.81
NGC_3201	154.403427	−46.412476	4.74	8.64	8.0250230	3.0374465	141.94
Gran_2	257.890000	−24.849000	15.84	8.59	−1.9641201	−1.6698459	−116.12
NGC_6779	289.148193	30.183472	10.43	8.34	0.5485667	2.5151089	103.26
NGC_6325	259.496327	−23.767677	7.53	8.00	−12.0979298	1.7598877	66.36
NGC_6293	257.542500	−26.582083	9.19	7.83	−3.0115925	−3.2291540	−159.04
NGC_6266	255.304153	−30.113390	6.03	7.32	−5.4375876	2.1811825	52.46
NGC_6139	246.918466	−38.848782	10.04	6.94	−6.1475598	2.5548822	123.74
NGC_6539	271.207276	−7.585858	8.16	6.78	−6.4126601	4.3415298	171.03
NGC_6517	270.460750	−8.958778	9.23	6.76	−4.6483533	−0.7924843	−38.58
NGC_6316	259.155417	−28.140111	11.15	5.76	−6.6254312	1.4319090	85.36
IC_1276	272.684441	−7.207595	4.55	5.67	−5.2491931	0.0734359	16.89
NGC_6355	260.993533	−26.352827	8.65	5.43	−3.1045387	3.6145579	129.12

Continued

NGC_6304	258.634399	−29.462028	6.15	5.38	−3.2467442	2.6895913	67.94
NGC_5927	232.002869	−50.673031	8.27	4.86	−5.9737147	0.2206639	−0.19
NGC_5946	233.869051	−50.659713	9.64	4.19	−5.2698419	1.7848184	91.45
NGC_6401	264.652191	−23.909605	7.44	3.98	−0.2254790	3.1178677	102.45
NGC_6440	267.220167	−20.360417	8.25	3.80	−4.0480299	−1.0291697	−44.79
Gran_3	256.256000	−35.496000	11.47	3.42	−1.9279856	3.3706196	188.73
NGC_6256	254.886107	−37.120968	7.24	3.31	−3.5584548	1.8938272	59.18
Pal_10	289.508728	18.571667	8.94	2.72	−8.3622493	0.4888675	19.20
Ter_2	261.887917	−30.802333	7.75	2.30	−6.3915840	−1.6914029	−56.78
HP_1	262.771667	−29.981667	7	2.12	−7.0349280	−7.5988281	−250.68
Gran_5	267.228000	−24.170000	4.91	1.84	−10.7390778	−0.2004053	−6.55
Pal_6	265.925812	−26.224995	7.05	1.78	−9.3142921	5.0606473	174.65
Ter_5	267.020200	−24.779055	6.62	1.69	−5.3372357	−1.0392659	−35.03
Ter_4	262.662506	−31.595528	7.59	1.31	−6.0171770	2.4625908	87.52
Ter_1	263.946667	−30.481778	5.67	0.99	−5.6574964	−0.1965494	−4.29
VVV-CL001	268.677083	−24.014722	8.08	0.78	−3.1906301	2.0647555	74.68
UKS_1	268.613312	−24.145277	15.58	0.76	−3.0226820	−0.6591470	−47.92
VVV-CL160	271.737500	−20.011111	6.8	0.30	−15.6280977	−6.4001518	−205.15
MASS-GC01	272.090851	−19.829723	3.37	0.10	−2.1965477	0.3430014	5.42
Liller_1	263.352333	−33.389556	8.06	−0.16	−8.6757093	0.5495440	20.84
MASS-GC02	272.402100	−20.778889	5.5	−0.62	−4.7191882	0.7329487	20.06
FSR_1716	242.625000	−53.748889	7.43	−1.59	−9.2559262	−3.5049283	−122.63
FSR_1735	253.044174	−47.058056	9.08	−1.85	−4.0720036	2.5688345	112.85
Ter_10	270.740833	−26.066944	10.21	−1.86	−5.6075545	4.6487625	218.15
Ter_9	270.411667	−26.839722	5.77	−1.99	−7.7646098	−1.9157936	−54.78
Ter_12	273.065833	−22.741944	5.17	−2.10	−5.6765625	4.0026695	94.65
Ter_6	267.693250	−31.275389	7.27	−2.16	−8.9621555	0.4812281	11.41
NGC_6544	271.833833	−24.998222	2.58	−2.20	−17.3750724	−7.0550301	−84.80
NGC_6749	286.314056	1.899756	7.59	−2.21	−6.6322304	−0.1851090	−4.41
Djor_1	266.869583	−33.066389	9.88	−2.48	−9.6932606	−0.3274483	0.23
Djor_2	270.454378	−27.825819	8.76	−2.51	−2.2577978	−2.1068361	−80.91
Lynga_7	242.765213	−55.317776	7.9	−2.80	−7.6266323	−2.5589874	−96.65
NGC_6553	272.322992	−25.908067	5.33	−3.03	−0.2035342	−0.5159640	−13.01
FSR_1758	262.800000	−39.808000	11.09	−3.29	0.5294556	3.7789394	185.42
NGC_6540	271.535657	−27.765286	5.91	−3.31	−4.2579551	1.8611737	53.04
NGC_6380	263.618611	−39.069530	9.61	−3.42	−3.9208846	0.0824420	3.84
Ton_2	264.042000	−38.556100	6.99	−3.42	−3.8553524	4.5830534	162.72

Continued

Patchick_126	256.410833	−47.342222	8	−3.83	−8.3804896	−0.2312930	−0.61
NGC_6453	267.715508	−34.598477	10.07	−3.87	−5.0134890	−3.1525475	−143.55
NGC_6760	287.800268	1.030466	8.41	−3.92	−3.7289854	−0.6933552	−27.43
NGC_6522	270.891958	−30.033974	7.29	−3.93	−4.3504848	−5.3973421	−185.16
Gran_1	269.651000	−32.020000	8.27	−3.98	−10.9776707	2.9971787	111.82
NGC_6528	271.206697	−30.055778	7.83	−4.17	−5.9878352	−0.8433308	−46.66
BH_140	193.472915	−67.177276	4.81	−4.31	−14.8882993	1.4003266	25.08
NGC_6712	283.268021	−8.705960	7.38	−4.32	−2.4494228	−4.9969944	−166.35
NGC_6838	298.443726	18.779194	4	−4.56	−4.0304540	1.5758897	31.61
NGC_6441	267.554413	−37.051445	12.73	−5.01	−5.9319594	−0.5151124	−32.60
BH_261	273.527500	−28.635000	6.12	−5.27	−1.4567879	−4.8480501	−134.64
NGC_6626	276.137039	−24.869847	5.37	−5.58	−8.0707163	−3.8364185	−98.34
NGC_6558	272.573974	−31.764508	7.79	−6.02	−4.4996159	−0.4322626	4.59
NGC_6642	277.975957	−23.475602	8.05	−6.44	−3.5592824	−1.6037873	−54.06
NGC_6569	273.411667	−31.826889	10.53	−6.68	−8.4187435	0.2319725	17.31
NGC_6388	264.071777	−44.735500	11.17	−6.74	−3.0005843	−0.3197011	−26.57
Pal_8	280.377290	−19.828858	11.32	−6.80	−5.9339544	−0.7175484	−33.56
NGC_6638	277.733734	−25.497473	9.78	−7.15	−4.7651555	0.4186629	18.20
NGC_6352	261.371277	−48.422169	5.54	−7.17	−4.8921400	−0.6296243	−0.74
NGC_6656	279.099762	−23.904749	3.3	−7.55	−0.6499270	−11.3075781	−155.93
NGC_6624	275.918793	−30.361029	8.02	−7.91	−6.1470558	−3.2581853	−130.32
NGC_4833	194.891342	−70.876503	6.48	−8.02	−8.4165855	−0.7001526	−49.48
NGC_4372	186.439101	−72.659084	5.71	−9.88	−6.7104895	2.6446347	57.59
NGC_6496	269.765350	−44.265945	9.64	−10.01	−9.6033491	−1.6935433	−52.84
NGC_6637	277.846252	−32.348084	8.9	−10.27	−7.4403317	2.0260546	75.70
NGC_6717	283.775177	−22.701473	7.52	−10.90	−5.8714507	0.7399592	20.20
NGC_6541	272.009827	−43.714889	7.61	−11.19	−7.7409477	−4.2616948	−119.10
NGC_2808	138.012909	−64.863495	10.06	−11.25	0.4735823	0.9252551	23.09
NGC_6652	278.940125	−32.990723	9.46	−11.38	−6.1790648	3.1761098	158.54
NGC_6397	265.175385	−53.674335	2.48	−11.96	−13.6757610	−11.6202306	−137.57
NGC_6681	280.803162	−32.292110	9.36	−12.51	−3.7237616	−3.2439020	−187.53
ESO_280-SC06	272.275000	−46.423333	20.95	−12.57	−2.7963703	−0.6078765	−79.25

The table gives the orbital parameters of 164 Galactic GC as derived from the Gaia EDR3 proper motions and radial velocities. The table contains all confirmed Milky Way GC with proper motion and radial velocity information.

The majority of the 164 GC are located in the central part of the Galaxy, so we selected GC from the table according to the following parameters: GC with galac-

tic longitude l in the range $0^\circ < l < 90^\circ$ and $270^\circ < l < 360^\circ$ (cut off the part behind the Sun). Thus, out of 164, 151 GC remain in the table. Next, we selected GC with a galactic latitude of $13^\circ > b > -13^\circ$ (92 GC) and separately, a distance to the Galactic plane from 1.4 kpc to -1.4 kpc (77 GC).

Table 2. The GC sample from the general table for the range of distances to the plane from −1.4 to 1.4 kpc contains 77 GCs.

Name	RA	*DEC*	R_{sun} kpc	*RV* km/s	μb [mas yr − 1]	*Dpl* kpc	*V*↑, *V*↓ km/s
NGC_6273	255.657486	−26.267971	8.34	145.54	3.6079414229	1.360	165
NGC_6342	260.291573	−19.587659	8.01	115.75	−1.4921814347	1.353	−36
NGC_6293	257.542500	−26.582083	9.19	−143.66	−3.2291539667	1.253	−159
Ter_3	247.162483	−35.339829	7.64	−135.76	2.8935818900	1.221	82
NGC_6139	246.918466	−38.848782	10.04	24.41	2.5548821981	1.213	124
NGC_6535	270.960449	−0.297639	6.36	−214.85	2.3670136697	1.152	31
NGC_6316	259.155417	−28.140111	11.15	99.65	1.4319090063	1.120	85
NGC_6517	270.460750	−8.958778	9.23	−35.06	−0.7924842869	1.087	−39
NGC_6325	259.496327	−23.767677	7.53	29.54	1.7598877255	1.048	66
NGC_6539	271.207276	−7.585858	8.16	35.19	4.3415298028	0.963	171
NGC_6366	261.934357	−5.079861	3.44	−120.65	−2.2913000101	0.950	−69
NGC_6355	260.993533	−26.352827	8.65	−195.85	3.6145578895	0.818	129
NGC_6266	255.304153	−30.113390	6.03	−73.98	2.1811824878	0.768	52
NGC_3201	154.403427	−46.412476	4.74	495.38	3.0374464690	0.712	142
NGC_5946	233.869051	−50.659713	9.64	137.6	1.7848183790	0.704	91
NGC_5927	232.002869	−50.673031	8.27	−104.09	0.2206639186	0.701	0
Gran_3	256.256000	−35.496000	11.47	94.87	3.3706196353	0.685	189
NGC_6304	258.634399	−29.462028	6.15	−108.62	2.6895912823	0.576	68
NGC_6440	267.220167	−20.360417	8.25	−69.39	−1.0291696623	0.547	−45
NGC_6401	264.652191	−23.909605	7.44	−105.44	3.1178677174	0.516	102
NGC_6121	245.896744	−26.525749	1.85	71.22	−3.5435439040	0.509	−10
IC_1276	272.684441	−7.207595	4.55	155.06	0.0734358716	0.449	17
Pal_10	289.508728	18.571667	8.94	−31.7	0.4888674927	0.425	19
NGC_6256	254.886107	−37.120968	7.24	−99.75	1.8938272225	0.418	59
Ter_2	261.887917	−30.802333	7.75	133.46	−1.6914029127	0.311	−57
HP_1	262.771667	−29.981667	7	39.76	−7.5988280550	0.258	−251
Pal_6	265.925812	−26.224995	7.05	177	5.0606473239	0.219	175
UKS_1	268.613312	−24.145277	15.58	59.38	−0.6591469714	0.208	−48
Ter_5	267.020200	−24.779055	6.62	−81.97	−1.0392659446	0.195	−35
Ter_4	262.662506	−31.595528	7.59	−48.96	2.4625907937	0.173	88
Gran_5	267.228000	−24.170000	4.91	−58.87	−0.2004052860	0.158	−7

Continued

VVV−CL001	268.677083	−24.014722	8.08	−327.28	2.0647554734	0.110	75
Ter_1	263.946667	−30.481778	5.67	57.55	−0.1965494344	0.098	−4
VVV−CL160	271.737500	−20.011111	6.8	245.28	−6.4001518435	0.036	−205
MASS−GC01	272.090851	−19.829723	3.37	−35.58	0.3430013522	0.006	5
Liller_1	263.352333	−33.389556	8.06	60.36	0.5495440375	−0.023	21
MASS−GC02	272.402100	−20.778889	5.5	−87.5	0.7329486715	−0.059	20
NGC_6544	271.833833	−24.998222	2.58	−38.46	−7.0550300926	−0.099	−85
Ter_12	273.065833	−22.741944	5.17	94.01	4.0026694574	−0.190	95
Ter_9	270.411667	−26.839722	5.77	68.56	−1.9157935705	−0.200	−55
FSR_1716	242.625000	−53.748889	7.43	−30.7	−3.5049282823	−0.206	−123
Ter_6	267.693250	−31.275389	7.27	137.15	0.4812280920	−0.274	11
NGC_6553	272.322992	−25.908067	5.33	−0.27	−0.5159639546	−0.282	−13
NGC_6749	286.314056	1.899756	7.59	−58.44	−0.1851090091	−0.292	−4
FSR_1735	253.044174	−47.058056	9.08	−69.85	2.5688344515	−0.294	113
NGC_6838	298.443726	18.779194	4	−22.72	1.5758897311	−0.318	32
Ter_10	270.740833	−26.066944	10.21	211.37	4.6487625204	−0.332	218
NGC_6540	271.535657	−27.765286	5.91	−16.5	1.8611736763	−0.342	53
BH_140	193.472915	−67.177276	4.81	90.3	1.4003266259	−0.361	25
Djor_2	270.454378	−27.825819	8.76	−149.75	−2.1068361326	−0.383	−81
Lynga_7	242.765213	−55.317776	7.9	17.86	−2.5589874141	−0.386	−97
Ton_2	264.042000	−38.556100	6.99	−184.72	4.5830533729	−0.417	163
Djor_1	266.869583	−33.066389	9.88	−359.18	−0.3274483325	−0.428	0
NGC_6656	279.099762	−23.904749	3.3	−148.72	−11.3075780998	−0.434	−156
NGC_6522	270.891958	−30.033974	7.29	−15.23	−5.3973420677	−0.499	−185
NGC_6397	265.175385	−53.674335	2.48	18.51	−11.6202306433	−0.514	−138
NGC_6626	276.137039	−24.869847	5.37	11.11	−3.8364185245	−0.522	−98
Patchick_126	256.410833	−47.342222	8	−122.14	−0.2312929821	−0.534	−1
NGC_6712	283.268021	−8.705960	7.38	−107.45	−4.9969944420	−0.556	−166
BH_261	273.527500	−28.635000	6.12	−60	−4.8480501092	−0.562	−135
NGC_6528	271.206697	−30.055778	7.83	211.86	−0.8433307918	−0.570	−47
Gran_1	269.651000	−32.020000	8.27	78.94	2.9971787050	−0.574	112
NGC_6380	263.618611	−39.069530	9.61	−1.48	0.0824420498	−0.574	4
NGC_6760	287.800268	1.030466	8.41	−2.37	−0.6933551606	−0.576	−27
FSR_1758	262.800000	−39.808000	11.09	227.31	3.7789394057	−0.637	185
NGC_6453	267.715508	−34.598477	10.07	−99.23	−3.1525475223	−0.680	−144
NGC_6352	261.371277	−48.422169	5.54	−125.63	−0.6296242777	−0.691	−1
NGC_6558	272.573974	−31.764508	7.79	−195.12	−0.4322626027	−0.817	5

Continued

NGC_6642	277.975957	−23.475602	8.05	−60.61	−1.6037873078	−0.903	−54
NGC_4833	194.891342	−70.876503	6.48	201.99	−0.7001526401	−0.904	−49
NGC_4372	186.439101	−72.659084	5.71	75.59	2.6446347474	−0.980	58
NGC_6624	275.918793	−30.361029	8.02	54.79	−3.2581853134	−1.104	−130
NGC_6441	267.554413	−37.051445	12.73	18.47	−0.5151123783	−1.111	−33
NGC_6638	277.733734	−25.497473	9.78	8.63	0.4186628947	−1.218	18
NGC_6569	273.411667	−31.826889	10.53	−49.83	0.2319725137	−1.225	17
NGC_6388	264.071777	−44.735500	11.17	83.11	−0.3197010757	−1.311	−27
Pal_8	280.377290	−19.828858	11.32	−39.68	−0.7175484457	−1.340	−34

2.1. Dependence of GC Velocities $V\uparrow$ and $V\downarrow$ on Galactic Latitude B

The sample for $13^{\circ} > b > -13^{\circ}$ consists of 92 GC (Table 1) In the original table, [7] the following GC parameters are given:

- *RA*: Right ascension
- *DEC*: Declination
- *l*: Galactic longitude
- *b*: Galactic latitude
- $R_{\odot}$: Distance from Sun
- *RGC*: Distance from the Galactic center
- *RV*: Radial velocity
- $\mu\alpha\cos\delta$: Proper motion in right ascension
- $\mu\delta$: Proper motion in declination
- $\rho\mu\alpha\mu\delta$: Correlation coefficient
- *X*: Distance from the Gal. center in direction of Sun
- *Y*: Distance from the Gal. center in direction of Solar motion
- *Z*: Distance above/below galactic plane
- *U*: Velocity in *X* direction
- *V*: Velocity in *Y* direction
- *W*: Velocity in *Z* direction
- *RPeri*: Average perigalactic distance
- *RApo*: Average apogalactic distance

As stated in the article [7] distances $R_{\odot}$ to GC are determined either by using eclipsing binaries [8] [9] or through fits of their color-magnitude diagrams (CMDs) with theoretical isochrones e.g. [10]-[13], by using variable stars that follow known relations between their periods and absolute luminosities like RR Lyrae stars e.g. [14] [15] Type II Cepheid [16] or Mira type variables [17]. Finally, it is possible to determine distances by comparing the magnitudes of main-sequence stars with stars of similar metallicity in the solar neighborhood, the so-called subdwarf method e.g. [18] [19] or kinematically by comparing line-of-sight and proper motion velocity dispersion profiles in GC e.g. [20]-[22]. The latter method has the advantage that the derived distance is not influenced by the reddening of

the cluster. For GC with accurately measured radial velocities and dispersion of proper motions, the distance to the GC can be determined by achieving a better fit with a theoretical cluster model e.g. [23].

RV radial velocities were calculated by [24] by combining literature data with ESO and Keck data archives. [25] also added radial velocities from Gaia DR2 and the Anglo-Australian Observatory (AAO) to the table. The radial velocities given in [26] were also added based on MUSE data. Own motions were added to the table from Gaia EDR3 or HST.

For this work, we used the following table parameters: *RA*, *DEC*, *l*, *b*, *RGC*, $\mu\alpha\cos\delta$, $\mu\delta$, *Z* and *W*.

The method for determining the velocity of the GC movement relative to the plane and center of the Galaxy is as follows: we find the position of the GC today (or rather at the time of observation) and in 1 year. The difference between these GC positions gives the velocity of movement for 1 year. Next, we convert this result into km/s. Although the parameters *l*, *b*, *RGC*, *Z* and *W* are given in the original table, in order to use the same calculation tools for the two GC positions, we recalculate them using the corresponding formulas.

We obtain *l* and *b* ourselves by converting coordinates using the formulas:

$$\sin(b) = \sin(\delta_{NGP}) * \sin(\delta) + \cos(\delta_{NGP}) * \cos(\delta) * \cos(\alpha - \alpha_{NGP}) \quad (1)$$

$$\tan(l_{NCP} - l) = \frac{\cos(\delta) * \sin(\alpha - \alpha_{NGP})}{\sin(\delta) * \cos(\delta_{NGP}) - \cos(\delta) * \sin(\delta_{NGP}) * \cos(\alpha - \alpha_{NGP})} \quad (2)$$

where:

- α and δ: equatorial coordinates of the GC,
- δ_{NGP} and α_{NGP} are the equatorial coordinates of the north galactic pole,
- l_{NCP}: Galactic longitude of the North celestial pole,
- l and b are the galactic coordinates of the GC.

The proper motions μl, μb were calculated based on $\mu\alpha$, $\mu\delta$ as follows: first, l and b are calculated based on the above formulas and then l' and b' (GC galactic coordinates in a year) using $\alpha' = \alpha + \mu\alpha$ and $\delta' = \delta + \mu\delta$. Next we get $\mu l = l' - l$, $\mu b = b' - b$.

Using μb, we obtain the velocity of movement $V\uparrow$ of the GC in the northern region relative to the Galaxy plane according to the formula:

$V\uparrow = (R_{\odot} + RV * SY/K) * \sin(b + \mu b) - R_{\odot} * \sin(b)$ where:

- $R_{\odot}$: Distance from the Sun
- *RV*: Radial velocity of GC
- *SY*: seconds in a year
- *K*: km in kpc

Thus, we obtained the velocities $V\uparrow$ of the GC motion in the direction orthogonal to the galactic plane. We, then sorted them in **Table 1** in descending order of *b*. For the southern region of the Galaxy, we will do the same with negative values of the indicated ranges *b* and denote the velocities $V\downarrow$. **Figure 1** and **Figure 2** show the GC velocities $V\uparrow$ and $V\downarrow$ in the northern and southern regions of the Galaxy.

Thus, it can be argued that the GCs of the northern region in the range $0^\circ < b < 13^\circ$ on average move away from the Galactic plane. The average velocity of the GC's receding from the Galactic plane in the northern region is 30.36 ± 15.29 km/s ($N = 42$). Similarly, GCs in the southern region of the Galaxy in the range $-13^\circ < b < 0^\circ$ on average move away from the Galactic plane at a velocity of 17.85 ± 13.76 km/s ($N = 50$).

Applying Student's t-test shows that the GC velocities $V\uparrow$ and $V\downarrow$ of the northern and southern regions of the Galaxy in the ranges $0^\circ < b < 13^\circ$ and $-13^\circ < b < 0^\circ$ differ at the level of 0.0205.

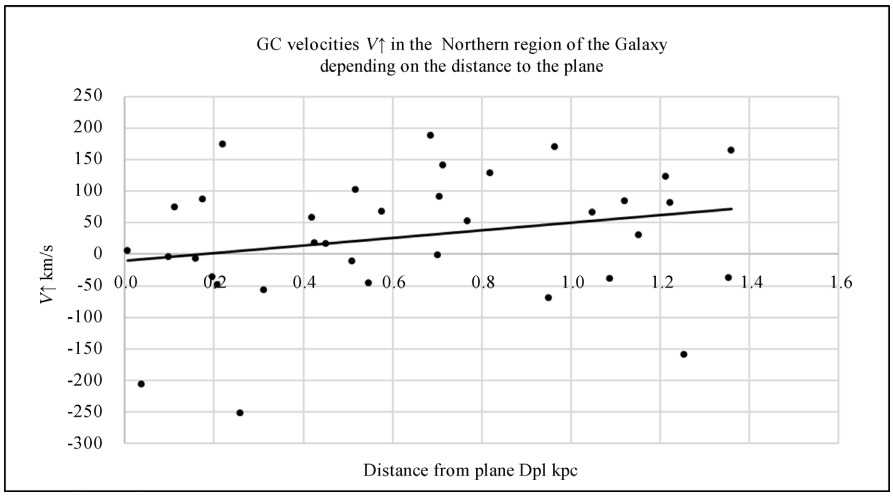

Figure 3. GC velocities V↑ in the northern region of the Galaxy depending on the distance to the Galactic plane. As can be seen from the figure, most GCs have a positive velocity, *i.e.* moving away from the galactic plane.

2.2. GC Velocities $V\uparrow$ and $V\downarrow$ Relative to the Galactic Plane Depending on the Distance to the Plane

In the previous section, we obtained the GC movement velocities depending on the galactic latitude *b*. Now let's move on to determining the GC velocities relative to the distance to the Galactic plane (*Dpl*). The GC sample from the general table for the range of distances to the plane from −1.4 to 1.4 kpc contains 77 GCs (**Table 2**). GC velocities $V\uparrow$ and $V\downarrow$ for the northern and southern regions of the Galaxy are shown in **Figure 3** and **Figure 4**.

On average, the GCs of the northern and southern regions of the Galaxy move away from the Galactic plane. The average velocity of the GCs receding from the plane for the northern region of the Galaxy is 27.74 ± 17.13 km/s ($N = 35$) and for the southern region -17.41 ± 14.51 km/s ($N = 42$). Applying Student's t-test shows that the GC velocities $V\uparrow$ and $V\downarrow$ of the northern and southern regions of the Galaxy for the distance ranges from the plane $0 < Dpl < 1.4$ kpc and $-1.4 < Dpl < 0$ kpc differ at the level of 0.0496.

It should be noted that similar results are obtained if we use the data from the original table: Z (Distance to the plane) and W (Velocity in Z direction) (**Figure**

5 and Figure 6). The difference in velocities $V\uparrow$ and $V\downarrow$ from the tabular data W is approximately 7.24 km/s, which can be attributed to the oscillation of the solar orbit ([27]-[32]).

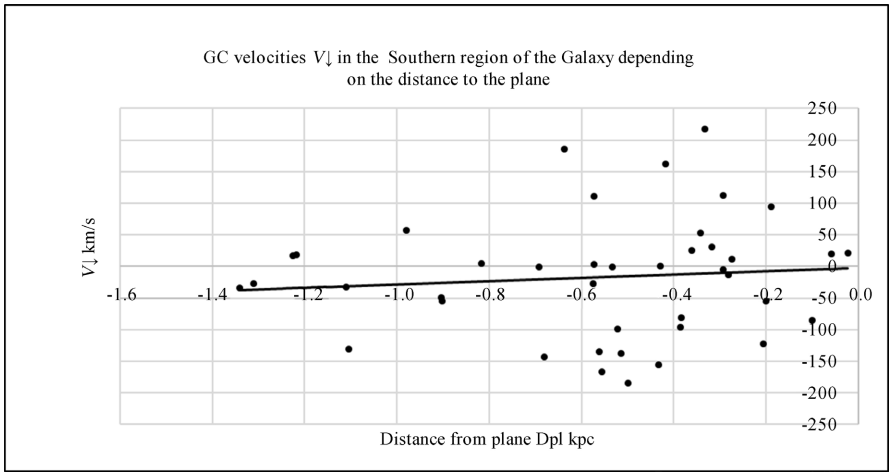

Figure 4. GC velocities V↓ in the southern region of the Galaxy depending on the distance to the Galactic plane Dpl. Most GCs have a negative velocity, *i.e.* move away from the plane.

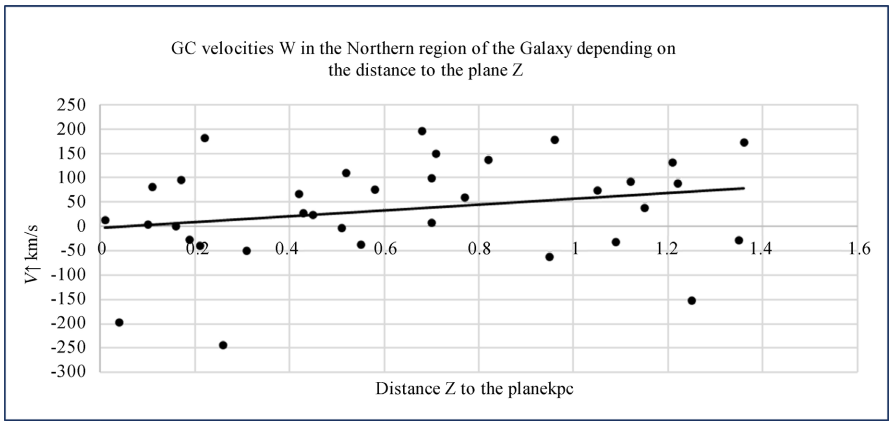

Figure 5. GC velocities W in the northern region of the Galaxy depending on the distance Z to the Galactic plane. Most GCs have a positive velocity, *i.e.* move away from the plane.

The dependence of the GC velocities $V\uparrow$ and $V\downarrow$ over the entire range $-1.4 < Dpl < 1.4$ kpc is shown in Figure 7. As can be seen from the figure, there is an obvious dependence between the parameters discussed. Let us evaluate the significance of the correlation. To do this, we use the value

$$t = R\sqrt{\frac{n-2}{1-R^2}} \tag{3}$$

which obeys the Student distribution. Here,

$$R(V, Dpl) = \frac{\sum\left(V_i - \langle V\rangle\right)\left(D_{pli} - \langle D_{pl}\rangle\right)}{(n-1)\sigma_V \sigma_{Dpl}} \tag{4}$$

- assessment of the correlation between the values of V and Dpl, σ_V and σ_{Dpl}: standard deviations of the corresponding values.

$$\sigma_V = \sqrt{\frac{\sum_{i=0}^{n}\left(V_i - \langle V\rangle\right)^2}{n-1}}, \quad \sigma_{Dpl} = \sqrt{\frac{\sum_{i=0}^{n}\left(Dpl_i - \langle Dpl\rangle\right)^2}{n-1}}, \tag{5}$$

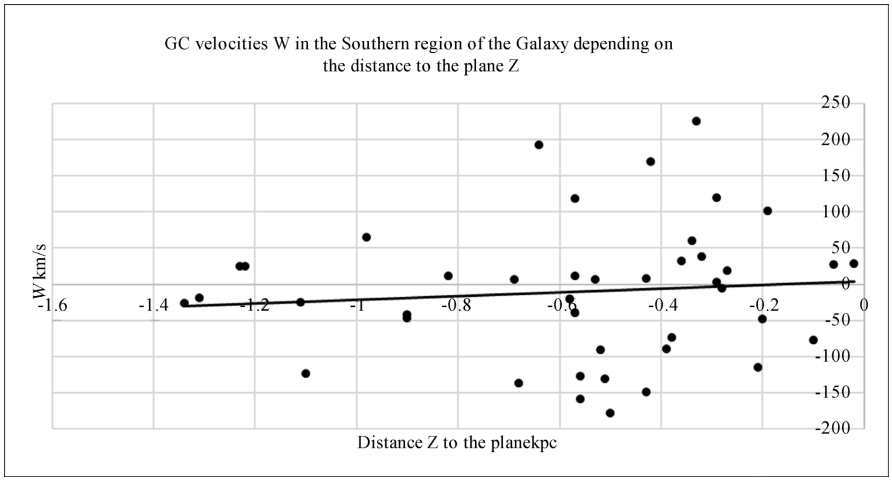

Figure 6. GC velocities W in the southern region of the Galaxy depending on the distance to the Galactic plane Z. Most GCs have a negative velocity, *i.e.* move away from the plane.

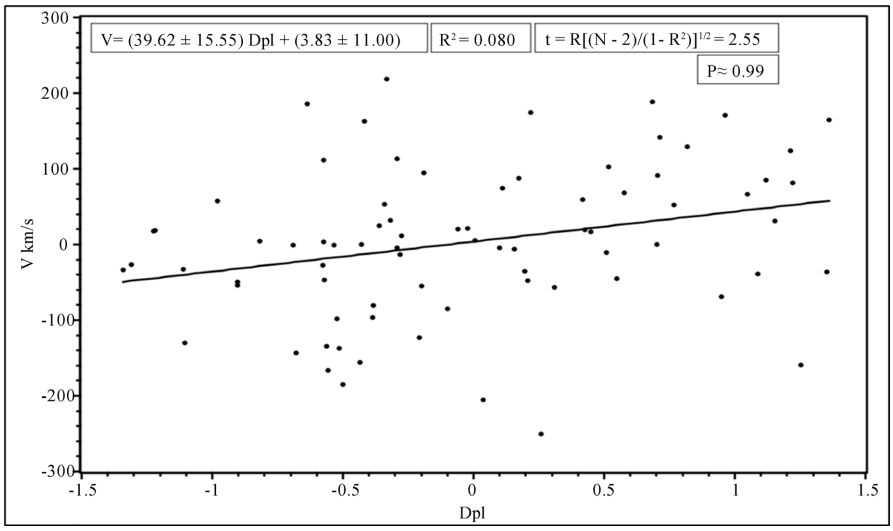

Figure 7. Dependence of GC velocities in the direction perpendicular to the Galactic plane on the distance of the GC to the plane for the entire range −1.4 to 1.4 kpc.

We get $t = 2.55$, from which it follows that the significance of the correlation is high $\alpha = 1 - P \approx 0.01$. Thus, we can conclude that GCs far from the Galactic plane, on average, have relatively high speeds of receeding from the Galactic plane.

2.3. Factor of Spatial and Kinematic Symmetry of GC

Figure 8 shows the plot of GC by distance Z from the galactic plane versus the velocities W at a distance of up to 4 kpc. As can be seen from the figure, GCs are

distributed quite symmetrically along the Z axis. Visually, it seems that the GCs are also distributed symmetrically by velocities W. In fact, the velocities of the northern and southern GCs differ significantly. The GC of the northern region is 23.02 km/s, and of the southern region - 10.48 km/s. The asymmetry value Asm = 12.54 km/s. We assume that this is due to the oscillation of the solar orbit (about 7 km/s relative to the plane). It is logical to accept that in order to obtain spatial symmetry, it is necessary to have symmetry by velocities as well, otherwise, over the past billions of years, spatial symmetry would have been broken.

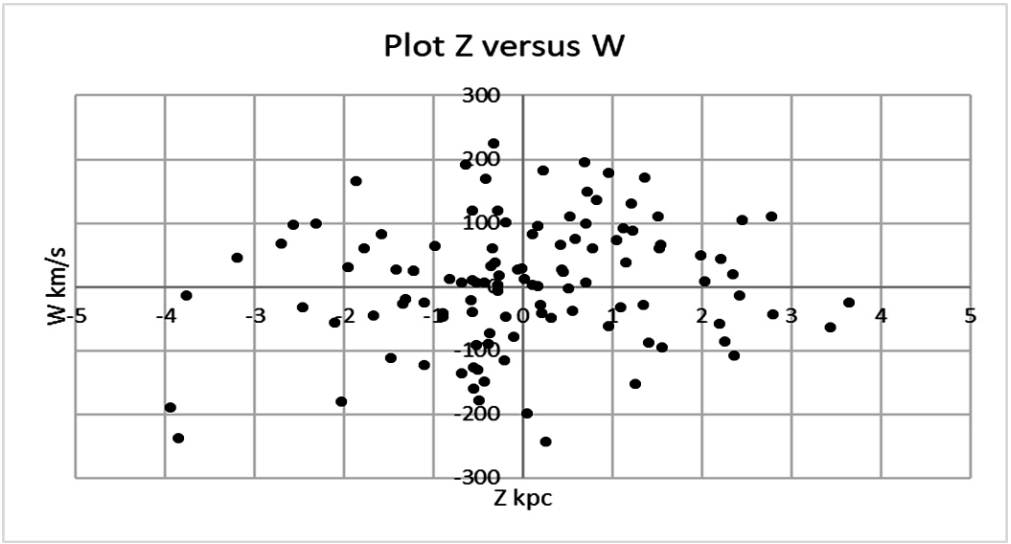

Figure 8. Plot Z versus W. We can see visual symmetry in Z direction.

2.4. GC Motion Relative to the Galactic Center

The result obtained in the previous sections that GCs on average move away from the Galactic plane suggests that it is possible that GCs on average can also move away from the Galactic center, so this work attempts to test this assumption.

Using the table data from 151 GCs, the distances of the GC from the center of the Galaxy $Rgal$ (Galactocentric distances) and the velocity of movement of the GC (VR) relative to the center of the Galaxy were calculated (it should be noted that this data is not in the original table). To do this, we calculated the distance of each GC from the center of the Galaxy for two points of location of these GCs: the "current" (or rather at the moment of observation) distance of the GC from the center $Rgal$ (Galactocentric distance) and the distance calculated after a 1 year $R'gal$. The difference between these distances gives us the velocity of movement of the GC relative to the center, *i.e.* $VR = R'gal - Rgal$. In the table, the current distance of the GC from the center of the Galaxy RGC is given rounded to the second decimal number, so we considered it appropriate to calculate these values ourselves. Using simple trigonometry, the velocities of globular clusters relative to the center of the Galaxy are calculated. The current distance of the GC from the Galactic center is calculated using the following formula:

$$Rgal = \sqrt{\left(D_{CL} * \sin(b)\right)^2 + \left(D_{GC} * \sin(l)\right)^2 + \left(D_{CL} * \cos(b) - D_{GC} * \cos(l)\right)^2} \quad (6)$$

where:

- D_{GC} (kpc): distance from the Sun to the center of the Galaxy;
- b : galactic latitude of the Globular Cluster (GC);
- l : galactic longitude of the Globular Cluster (GC);
- D_{Cl} : distance from the Sun to the center of the GC;
- $Rgal$: distance from the center of the Galaxy to the center of the GC.

The distance of the GC from the Galactic center in 1 year is calculated using the following formula:

$$R'gal = \sqrt{\left(D'_{CL} * \sin(b')\right)^2 + \left(D_{GC} * \sin(l')\right)^2 + \left(D'_{CL} * \cos(b') - D_{GC} * \cos(l')\right)^2} \quad (7)$$

where:

- $D'_{Cl} = D_{Cl} + RV$ distance from the Sun to the GC in a year;
- $b' = b + \mu b$: galactic latitude in a year;
- $l' = l + \mu l$: galactic longitude in a year;
- RV: radial velocity of the GC relative to the Sun.

The average velocity of the GC relative to the Galactic center for the range 0 to 12 kpc is 31.70 ± 14.74 km/s (N = 119). At the same time, with increasing distance this speed decreases and for a distance of 90 kpc it reaches about 9 km/s, which can be attributed to the gravitational influence of the galaxy on the GC. Based on the calculations obtained, it can be assumed that GCs, on average, are probably also moving away from the Galactic center.

3. Conclusion and Discussion

Thus, within the framework of this work, the velocities of movement $V\uparrow$ and $V\downarrow$ of the globular clusters of the northern and southern regions of the Galaxy were calculated depending on the Galactic latitude b and the distance to the Galactic plane. The GC motion velocities relative to the Galactic center were also calculated. The following results were obtained:

• GCs of the northern region in the range $0^\circ < b < 13^\circ$ on average move away from the Galactic plane. The average velocity of the GC's receding from the Galactic plane in the northern region is 30.36 ± 15.29 km/s (N = 42).

• GCs in the southern region of the Galaxy in the range $-13^\circ < b < 0^\circ$ on average move away from the Galactic plane at a velocity of 17.85 ± 13.76 km/s (N = 50).

• GCs in the northern region of the Galaxy in the range of distances to the plane from 0 to 1.4 kpc on average move away from the plane of the Galaxy. The average velocity of receding of the GC in the northern region from the Galactic plane is 27.74 ± 17.13 km/s (N = 35).

• GCs in the southern region of the Galaxy in the range of distances to the plane from 0 to 1.4 kpc on average move away from the plane of the Galaxy. The average velocity of receding of the GC in the southern region from the Galactic plane is

17.41 ± 14.51 km/s (N = 42).

• The average velocity of receding of the GC from the Galactic center for the range 0 to 12 kpc is 31.70 ± 14.74 km/s (N = 119) and decreases with increasing distance.

Thus, it can be stated that the population of the second type of Galaxy, using the example of Globular clusters, at least in the central part, is possibly expanding, which gives reason to assume that the Galaxy itself is also expanding within the specified limits. By accepting this idea, we can calculate the sizes of galaxies depending on their age, for example, if the expansion speed is 10 km/s, then in a billion years the size of the galaxy will be approximately 20 kpc, which is quite consistent with the average galaxy size. The latter suggests that the accepted age of our galaxy should possibly be revised. This seems unlikely as it is not consistent with current theory, so it can be considered a preliminary result requiring further study both theoretically and observationally.

Acceptance of this idea can explain the discrepancy between the ages of our galaxy and the massive galaxies discovered by the James Webb Space Telescope (JWST) [33], whose age is estimated to be less than 1 billion years. Refinement of the results obtained and further research will be facilitated by the presence of a larger number of studied clusters with more accurate parameters.

Data Availability

For the research in this paper, we used the table of 164 well-studied Globular clusters of the Milky Way Galaxy given by [7]. The table gives the orbital parameters of Galactic globular clusters as derived from the Gaia proper motions and radial velocities. The table contains all confirmed Milky Way globular clusters with proper motion and radial velocity information. The distances and the other parameters of Galactic globular clusters can be obtained from the following webpage: https://people.smp.uq.edu.au/HolgerBaumgardt/globular/orbits.html.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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