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**EPHEMERIDES OF THE FIVE OUTER PLANETS IN HELIOCENTRIC  
RECTANGULAR COORDINATES BASED ON DE200**

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# Ephemerides of the five outer planets in heliocentric rectangular coordinates based on DE200

## 1. Introduction

The 3 heliocentric equatorial rectangular coordinates of the 5 outer planets, X, Y, and Z, produced by a numerical integration, have been scanned by frequency analysis and an approximation has been performed under the form of mixed series of the time, including Fourier and Poisson terms. Fourier elements are purely periodic terms expressed as sums:  $C \sin(\nu t) + S \cos(\nu t)$ ; Poisson elements are mixed terms expressed as products and sums:  $t^n [C \cos(\nu t) + S \sin(\nu t)]$ ;  $C$  and  $S$  are numerical coefficients,  $\nu$  is a frequency,  $t$  is the time,  $n$  is the degree of Poisson elements. The algorithm for the construction of the series by frequency analysis is described in (Chapront, 1994).

The preliminary source is JPL's development ephemeris DE200/LE200 (Newhall et al., 1983) or, more precisely, an extent of DE200 over 558 years which is obtained using Moshier's integration tools (Moshier, 1992). The approximate solution is valid only on a finite time interval. For the reference system of the source we refer to mean equator and equinox J2000 (Standish, 1982).

The general form of the solution is written explicitly, for practical use:

$$X, Y \text{ or } Z = C_0^{[0]} + C_0^{[1]} T + \sum_{n=0}^2 \sum_{k=1}^{K_n} T^n \left( C_k^{[n]} \cos(\nu_k t) + S_k^{[n]} \sin(\nu_k t) \right) \quad (1)$$

$T$  is the time (TDB) in Julian centuries from J2000:  $T = (\text{Julian Date} - 2451545.0)/36525$

$t$  is the time (TDB) in Julian years from J2000:  $t = (\text{Julian Date} - 2451545.0)/365.25$

The time interval covers the Julian dates 2338032.5 (1689/03/19) to 2542032.5 (2247/10/01). Series should not be used outside this interval of validity.

$\nu_k$  are the frequencies measured in radian/year.

$C_k^{[n]}$  and  $S_k^{[n]}$  are the coefficients in units of  $10^{-10}$  AU (per century if  $n=1$ , or per century<sup>2</sup> if  $n=2$ ).

The upper bounds  $K_n$  depend on the planet and on the associate power of the time  $n$ .

On the whole time interval the error maximum which is obtained by comparison between the source and its approximation is given by the table 1:

**Table 1.** Ephemerides of the 5 outer planets over 558 years. Precision and number of terms of the approximations.

Body	Error maximum in X, Y, Z (Astromical Units)	$K_0$	$K_1$	$K_2$
Jupiter	$5 \cdot 10^{-7}$	154	44	16
Saturn	$9 \cdot 10^{-7}$	130	41	19
Uranus	$1 \cdot 10^{-6}$	102	19	6
Neptune	$2 \cdot 10^{-6}$	96	15	4
Pluto	$3 \cdot 10^{-6}$	66	20	10

**Table 2.** Ephemerides of the five outer planets in heliocentric, equatorial, rectangular coordinates (mean equator and equinox of DE200).

JUPITER

		X		Y		Z		
k	n	C_k[n]	S_k[n]	C_k[n]	S_k[n]	C_k[n]	S_k[n]	Nu_k
0	[0]	-3658015942		-908357166		-300271978		0.
	[1]	3211736		-12066362		-5380492		
1	[0]	4891337	5430776	-9059458	4045908	-3979137	1598300	0.0168745727060282
	[1]	-1952368	3224556	-3665363	-6161184	-1519962	-2703058	
2	[0]	589280	-62004	-1226982	1326111	-536148	568311	0.0319163179770344
3	[0]	-132797	113059	332715	-538044	144358	-232591	0.0404897860926306
4	[0]	19390	-8208	-31003	153367	-13456	65630	0.0595473299932462
5	[0]	-2479	-51303	154576	368773	65961	157222	0.0831987723231718
	[1]	-170149	190549	249291	-236183	108588	-106146	
6	[0]	-14177274	-32784827	-28623327	13932421	-12074567	6670491	0.1015656301267251
	[1]	-3789129	1413684	2551178	1957155	1164465	819456	
7	[0]	12762505	226609	-4837955	12330917	-2405339	5249055	0.1121334694975955
	[1]	547155	1481967	-2013999	-2660987	-879208	-1179904	
8	[0]	-62226	-41759	-601831	240767	-255949	106231	0.1235484250413803
9	[0]	38451	-38927	103878	-40998	43472	-16957	0.1380033981088614
10	[0]	6892	-67712	62422	39405	26942	18451	0.1534434914458037
11	[0]	-75	8062	-21151	-17198	-9222	-7580	0.1694333239035300
12	[0]	35355	38181	70566	-4376	30386	-2939	0.1895181584594278
13	[0]	-743715	-251198	-403257	598432	-166123	265466	0.2002642151969322
14	[0]	5834437	-10339387	9606367	9534188	3806370	4385708	0.2140513638608579
	[1]	1033031	-590411	-1874404	575478	-835406	235620	
	[2]	514744	-29792	-180518	-472533	-83894	-204253	
15	[0]	160903	-61277	-282564	-163689	-122933	-69902	0.2282692683160305
16	[0]	-27903	23114	66255	2167	28792	688	0.2391180221674930
17	[0]	4501	-5373	-15639	12832	-6785	5553	0.2594200270243392
18	[0]	-7016	15969	7639	-40047	3504	-17544	0.2773387700991547
19	[0]	12123	-71452	49781	137809	20807	61532	0.2898870950096423
20	[0]	9304	220632	-262203	-258243	-112815	-119757	0.2988785450891279
21	[0]	-326815	-368979	836570	374605	369053	187133	0.3074463122377075
22	[0]	-285560	1568528	-1374181	-462165	-548097	-222596	0.3260929459480317
	[1]	61071	-241375	291550	243626	110389	123427	
	[2]	227305	162244	-116416	352218	-65158	140646	
23	[0]	132035	23450	116510	219543	39775	92330	0.3428930094327709
24	[0]	-45107	4887	-87029	-68971	-33182	-29857	0.3524288275557115
25	[0]	11180	1421	46242	3234	18448	1726	0.3676619945918164
26	[0]	55636	74415	46443	-53844	16908	-25824	0.3817149836030239
27	[0]	-38712	-7953	29506	-14698	13883	-4384	0.4024967272931009
28	[0]	737722	-3325874	-1725701	1468892	-912453	541637	0.4182255664674069
29	[0]	5843515	17000877	-16425950	5641739	-7208900	1880856	0.4281067291965077
	[1]	-2114864	879909	-1266263	-2982111	-450528	-1332322	
30	[0]	-110808	282843	-713054	221824	-319044	77631	0.4373541005020147
31	[0]	27829	-71864	150036	-117804	67370	-49093	0.4560888031675395
32	[0]	539822	432225	-319385	741980	-155058	309230	0.4797023746036813
	[1]	353284	-620503	706907	178082	295983	93413	
	[2]	-261070	-393195	329623	-469610	151911	-193312	
33	[0]	-2161367	-547925	176106	-2360409	138737	-1001848	0.5007107300722267
34	[0]	27247697	-10878578	11956310	25892704	4272604	11389311	0.5164419295757459
35	[0]	42877248480	-29362030594	27366424342	39132999157	10686125728	17489248357	0.5296606590588865
	[1]	-15857296	-20344255	19186229	-13052624	8755482	-9908361	
	[2]	6609281	13149967	-10297853	6131752	-4439009	2280289	
36	[0]	-18516226	26000654	-21956172	-17721375	-8891106	-8274169	0.5451799187785868
37	[0]	924882	-10894893	8857638	2001907	3741179	1161552	0.5595376466726170
38	[0]	27311120	29858821	-26928769	14296744	-12217212	5123580	0.5795066100144535
	[1]	13030129	-18873913	10742323	12477743	4123021	5837654	

39	[2]	-7424534	-11497916	9860547	-3566473	4394376	-1162013	
	[0]	-26277687	-24566747	22551607	-14225886	10328130	-5247184	0.5911608643334181
	[1]	8339866	-11546546	6481932	8138775	2473924	3793057	
40	[0]	-712821	106326	116149	-425425	75173	-183273	0.6154942605989902
41	[0]	10367622	10279698	-8594103	9404066	-3937577	3712537	0.6326027345940838
	[1]	897045	857895	-751707	469816	-332572	171768	
42	[0]	189069	-432469	40216	165708	-8464	80857	0.6444812066531010
	[1]	358961	188063	-197366	119155	-93776	37030	
43	[0]	2801	-42321	23044	13212	9231	7153	0.6631203366491857
44	[0]	4336	3618	-871	-1752	-434	-1180	0.6824152589010221
45	[0]	-14481	-6624	4573	-1496	2554	-8	0.7002707215510490
46	[0]	-223890	106356	-2013	-41001	13805	-21357	0.7195602591163895
	[1]	28954	129738	-23285	-9336	-9672	-11954	
47	[0]	500290	-303873	-27592	125875	-40399	71687	0.7280600120460897
48	[0]	729018	-876869	-461257	537352	-184892	325523	0.7385877731868745
	[1]	-549774	403499	-445388	-787700	-178960	-329235	
49	[0]	-154224	-136331	129548	-90101	64599	-32148	0.7506622252123309
50	[0]	36827	21410	-22046	16972	-12019	7006	0.7602186192346818
51	[0]	-9432	-929	4761	-3712	2630	-1835	0.7714697369886172
52	[0]	2272	-244	-1058	1139	-553	579	0.7851226034217180
53	[0]	236	2440	694	90	191	-135	0.8150362349770407
54	[0]	2171	-25731	-8199	18101	-2071	8952	0.8291920856012017
55	[0]	-6488604	1912961	-2051708	-5704251	-640826	-2468602	0.8459901559232306
	[1]	133871	-10089	-90464	3174	-43566	7399	
	[2]	3748	19859	25943	-57668	8170	-24731	
56	[0]	41412	22074	-6939	-4045	-5698	-1697	0.8578592213260567
57	[0]	574	1501	-732	4283	-255	1685	0.8738246080594192
58	[0]	2322	-1798	335	937	88	501	0.8963147077496537
59	[0]	-43604	-1899	4040	-39896	2661	-17151	0.9105458422489332
60	[0]	3596	-6271	379	5996	286	2760	0.9259391061890530
61	[0]	-999582	6287537	-5679601	-791405	-2413314	-507432	0.9494173054851961
	[1]	111599	-339713	235481	52027	98992	33925	
	[2]	-33602	-140395	93339	-35641	41369	-10865	
62	[0]	149940	-187453	95997	203410	38908	91533	0.9614421422806174
63	[0]	46262	123227	-97700	-14018	-43879	-8187	0.9766842863215204
64	[0]	-150852	-63931	82864	-16270	39997	-7673	0.9902969827486889
65	[0]	580431	130968	-306415	215177	-145258	96440	1.0007147457558208
66	[0]	-315446	-113604	191678	-91901	90254	-41025	1.0094608196461621
	[1]	-3456	-446353	229052	185524	103258	88674	
67	[0]	-189618	113597	8806	-140678	6615	-64661	1.0246980386783211
68	[0]	4202483	3000173	-2459447	3363962	-1179328	1385544	1.0482030530764612
	[1]	1203874	-292900	70065	779465	3811	351179	
69	[0]	735702407	-1021641460	944902088	667150510	387126729	310854521	1.0592824949737543
	[1]	-225227	-2656169	2070353	-678917	860531	-321583	
70	[0]	-906103	1248865	-1249024	-614151	-510434	-296157	1.0735437556293621
71	[0]	133104	-244102	224418	-12870	91960	2555	1.0875704154537504
72	[0]	-98191	334119	-93120	114027	-39453	36051	1.1091289342301658
	[1]	131527	1551	58039	-54878	19569	-21191	
	[2]	65753	-188377	68757	-76650	28565	-25385	
73	[0]	61867	-343846	16261	-113012	8972	-35330	1.1225031990563263
74	[0]	-7347	137455	17960	22121	5845	4618	1.1328877109810458
75	[0]	11044	-88733	-25019	37631	-8977	18971	1.1464066922869334
76	[0]	11350781	-248125	270190	10489566	-145232	4511204	1.1622993228682923
77	[0]	-52127	35850	-14691	-77957	-5084	-33671	1.1728440239417584
	[1]	-12008	23292	-2942	-7282	-1291	-3563	
78	[0]	4294	460	-3058	3439	-1373	1474	1.1878668274609869
79	[0]	-1289	-734	1786	-2248	786	-941	1.1998692758026896
80	[0]	361	-793	308	-1262	122	-515	1.2317935880659059
81	[0]	-195	2534	-191	3923	-67	1609	1.2448441509199817
82	[0]	-5385	-19904	6349	-3489	3158	-1221	1.2560282933480911

83	[0]	413790	-613072	546872	412919	228594	191066	1.2653944427657104
	[1]	-20115	4841	-30066	-2156	-12194	-733	
84	[0]	-56810	-2443	14410	-37878	7539	-15830	1.2776927606634534
	[1]	-883	-20034	8211	10587	3489	5153	
85	[0]	-2444	1465	414	793	279	259	1.2924980461987274
86	[0]	864	-632	-623	-218	-312	-55	1.3014788911147197
87	[0]	26233	-115536	1588	-54448	260	-17749	1.3673745438817879
88	[0]	-366768	241272	-241508	-348534	-93295	-154126	1.3764442873088090
	[1]	-4898	-22923	39935	-25211	16711	-10168	
89	[0]	7481	-4670	-7877	-4002	-3598	-1348	1.3867469996002664
90	[0]	-2408	1756	2965	1290	1336	416	1.3958662188525488
91	[0]	972	-751	-912	-28	-417	39	1.4068178503492994
92	[0]	-20343	4804	-6579	-18594	-2298	-8037	1.4396065958679622
93	[0]	894	1313	1992	632	793	162	1.4496940872610145
94	[0]	-1983	-4631	-7582	723	-2974	660	1.4625845924962999
95	[0]	648492	510288	-503142	612739	-227097	254982	1.4790870471301645
	[1]	-7847	5399	-12816	-32834	-5768	-13533	
	[2]	-5935	4107	3696	-8454	1585	-3763	
96	[0]	471	-326	1178	-492	455	-210	1.5004111597792062
97	[0]	-1102	5980	-5712	-389	-2409	-319	1.5140608680143952
98	[0]	235	-531	427	-154	168	-42	1.5277453924778683
99	[0]	1530	1846	-2090	2162	-918	867	1.5510420454912401
00	[0]	-8695	-5270	3702	-11973	1786	-4877	1.5653775377343770
01	[0]	108442	13977	-7635	130460	-5580	54970	1.5750243622459430
02	[0]	12988439	-44123991	40567288	11522384	17076170	6015693	1.5888946239094504
	[1]	-297436	-96470	75756	-224551	37973	-97866	
	[2]	-140095	49206	-15492	-114871	-4072	-51280	
03	[0]	-213784	360331	-204961	-174648	-85958	-85816	1.5999174688094493
04	[0]	34848	-82622	33382	30061	14595	15488	1.6100691344943834
	[1]	43010	10308	-12996	14235	-6844	6576	
05	[0]	-1221	-3776	845	910	489	461	1.6263710325060152
06	[0]	554	745	-310	-340	-171	-141	1.6392210890659527
07	[0]	20026	-16502	-3852	-9369	-2306	-3026	1.6820002884969334
08	[0]	813659	-336143	300160	724773	109085	319540	1.6916922798012188
	[1]	1602	-17457	27667	-10914	11558	-4357	
09	[0]	-5880	742	-5245	-7508	-2092	-3141	1.7051957386154943
10	[0]	1260	203	1855	1795	753	722	1.7137017697983383
11	[0]	-181	118	893	-230	356	-133	1.7715707154892435
12	[0]	715	-2305	-3568	635	-1416	471	1.7804397794409668
13	[0]	100206	-23631	4854	93727	818	43069	1.7946296659726320
	[1]	4224	-2685	2729	-6839	1031	-2737	
	[2]	84	2460	356	-441	163	-287	
14	[0]	-3928	2396	-1944	-4367	-655	-1968	1.8082885005321963
	[1]	-1281	-1070	1425	-1360	663	-508	
15	[0]	-434	-572	-639	581	-222	273	1.8824124715680111
16	[0]	5875	-12921	-96	9965	681	4780	1.8981641851181350
	[1]	3309	-927	-4565	1029	-1995	584	
17	[0]	-14234	16692	-15551	-9091	-6255	-4365	1.9094415371356366
	[1]	-5299	-4657	1995	-4393	1032	-1732	
18	[0]	-215	526	-123	-7	-42	-32	1.9243893317056575
19	[0]	-1607	1027	-1015	-1384	-397	-623	1.9690057130935361
20	[0]	907	-182	55	-552	-12	-217	1.9888685259410335
21	[0]	80093	1775	-15336	49616	-8505	21779	2.0075896690458515
	[1]	3675	886	9437	1003	3841	302	
	[2]	-2718	2441	1312	2111	647	750	
22	[0]	-749	2213	3067	2387	1321	864	2.0177406604319246
23	[0]	82	445	-97	12	-47	-15	2.0452450030168667
24	[0]	939	145	-364	1452	-175	622	2.0918668035808388
25	[0]	29763	-11270	1340	26747	35	12241	2.1052596067061962
	[1]	-752	-10176	11464	-2886	4981	-1015	

126	[0]	-122433	-1948247	1789021	-131787	769924	-8458	2.1185267640432053
	[1]	-14746	-2745	3642	-14273	1472	-6101	
	[2]	-1381	-4337	4157	-766	1816	-296	
127	[0]	207	2382	-2373	455	-1016	119	2.1318821280894955
128	[0]	317	-2045	-1566	2287	-544	1086	2.2071860619320218
129	[0]	45591	-42445	35109	42326	14234	19311	2.2209783021218397
	[1]	100	-868	334	-2387	63	-853	
	[2]	-274	556	48	-449	-11	-223	
130	[0]	347	-11	-113	-232	-65	-97	2.3082627901909945
131	[0]	16054	-5418	3307	5345	1043	2606	2.3219886353180517
	[1]	-19	-205	4127	-783	1741	-387	
	[2]	-647	309	-95	84	-24	13	
132	[0]	2409	-2117	-2607	-228	-1170	136	2.4200734218253461
	[1]	19	-536	414	216	214	119	
133	[0]	2201	3681	-3051	2808	-1347	1419	2.4294275957278497
134	[0]	-423	745	-737	-631	-315	-318	2.4385609820738123
135	[0]	300	-1484	-1399	755	-530	425	2.5260130486716892
136	[0]	5490	-1919	480	4689	156	2132	2.5361042359568997
	[1]	215	-174	275	-263	81	-64	
137	[0]	308	-156	185	292	82	121	2.5459330159552604
138	[0]	5463	46	202	1602	-48	766	2.6374295145352566
	[1]	581	381	1106	451	460	165	
139	[0]	-36662	-85712	78236	-34663	34443	-12759	2.6481663000165407
140	[0]	1477	-1072	-1320	-336	-622	-3	2.7397040327703399
141	[0]	1659	-2071	2391	2294	963	1120	2.7490048220101793
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NEPTUNE

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93	[0]	149	-16	70	137	24	69	6.6811483956904603
94	[0]	14	35	-47	-48	-19	-18	8.4710967963441863
	[1]	1	-1	-17	-7	-7	-4	
95	[0]	-17638	555	-991	-16049	673	-7250	10.2132840866995910
96	[0]	-44	-259	211	-59	89	-24	12.5662764645159580

PLUTO

k	n	C_k[n]	X	S_k[n]	C_k[n]	Y	S_k[n]	C_k[n]	Z	S_k[n]	Nu_k
0	[0]	101045891905		110312086224		6172492792		0.			
	[1]	2736962357		7289921703		8356828229					
1	[0]	-197631754827	306850452168	-363706825084	-174047739469	-83742488844	-166197114948	0.0255535185296511			
	[1]	-10339882709	3627560682	-1704596538	16082008148	-2615797675	26582875457				
	[2]	4555881844	5354987944	14163087849	13295578846	16544976961	15318697408				
2	[0]	12877551757	9141005248	38823958976	14074786713	47081142550	15934841957	0.0383093966256461			
3	[0]	-20363081906	43534352230	-68888048997	-6054817551	-37922256273	-13665923314	0.0512632279013590			
4	[0]	11372859069	-7331041505	34135169446	-14164330338	35562426110	-15256543947	0.0629625800045217			
5	[0]	-25223811753	30334977886	-76993608077	67207355885	-78022096909	72709750549	0.0739104871604531			
6	[0]	19031032676	-21606847641	49490563510	-67837042251	54793488046	-76660221358	0.0843726142307477			
	[1]	9888109415	13390931761	31569755508	36949340015	35801709881	41063108577				
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7	[0]	77016900	8576436595	-758303524	19868503441	945693837	21114141886	0.1009656667626818			
8	[0]	-425710709	-2201772586	-2981443460	-6781825029	-3324565933	-7783206250	0.1181216342983851			
	[1]	2255988361	-245384099	5983679140	-939391729	6514267045	-1323842110				
	[2]	531179571	1086625691	2182247914	3044397909	2484824490	3408389022				
9	[0]	670122662	438458646	1753307958	718209879	2047795531	636335929	0.1384952768343311			
0	[0]	-179746215	-90394676	-766063009	-205567765	-854408253	-261725146	0.1499201895782055			
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2	[0]	38739517	9002149	12071193	-2098061	15714901	-32081340	0.1760768320056049			
3	[0]	-2332129	6073325	-5475022	19141973	-5216109	20872520	0.1900452184842649			
4	[0]	8137788	-2826068	-3014741	-6719062	-5256740	-14189611	0.2024941844674784			
5	[0]	18559203	-16541614	25112499	27558953	14213163	19938478	0.2134752084935937			
6	[0]	1940133	-1267576	-1439934	-1986889	-2525015	-3851133	0.2269557049635166			

	[1]	1917476	-1704590	4921317	-5434051	4782139	-6305807	
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19	[0]	-135658	-8463	-393590	160618	-448155	267162	0.2643717493874742
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22	[0]	55997	-115242	-44421	-45883	-43549	-47825	0.3037412654012783
23	[0]	-14892	15253	52487	23252	43486	48497	0.3142803959054077
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27	[0]	-4324	14942	537	2320	8817	-1258	0.3768935755307548
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30	[0]	719443	-70760	86542	684112	3209	279550	0.4267968486470127
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34	[0]	-3424	9654	4992	7807	583	1356	0.4869141744280314
35	[0]	-449	-1794	3826	-7250	-2319	-7298	0.5001714317315645
36	[0]	15872	9071	15995	31749	10331	14516	0.5137491938947873
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38	[0]	-7558	61741	-13579	-15470	9629	-26943	0.5428748902518665
39	[0]	-5153	-16254	1129	1453	-5621	9705	0.5545763246422408
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40	[0]	-472	-1295	65	-1013	81	865	0.5737334589484931
41	[0]	1071	-818	-1860	-1756	-2076	-217	0.6240874769868805
42	[0]	35210	26306	-24283	31193	-11240	11870	0.6381677442023816
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46	[0]	-6012	8879	923	-5393	1314	-3852	0.8466308769723183
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49	[0]	5058	-2711	-831	-3667	-1554	-139	0.9284980837327494
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	[1]	453	513	-533	-1316	-1407	-442	
52	[0]	-1452	2161	-2167	-2392	843	-1017	1.0358203937225836
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54	[0]	-13391	43036	-26981	-8012	-15174	6191	1.0698620958167548
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56	[0]	10855	-624	671	9748	207	3846	1.1622398168028405
	[1]	-33	92	-124	-554	-92	-612	
57	[0]	448	-1008	1081	183	623	-187	1.2654499680761597
58	[0]	-207	526	176	-733	246	-400	1.3757220045803040

59	[0]	638	340	-422	36	44	18	1.4777197679290477
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62	[0]	30	-1843	2162	314	1153	512	2.1185453910327063
63	[0]	4845	477	-393	4358	-362	2072	3.3406128168607023
64	[0]	-5939	-29727	27855	-4133	12163	-1725	6.2830758108873654
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65	[0]	-223	149	91	102	231	420	8.4710959288534031
66	[0]	-17640	-47	-831	-15721	782	-7065	10.2132856585962150
	[1]	165	60	-38	154	112	136	
	[2]	20	46	112	-30	119	10	

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