ENCOUNTERS OF THE SUN WITH NEARBY STARS IN THE PAST AND FUTURE

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Abstract. The relative space motions of the Sun and nearby stars are considered. The coordinates and velocities of the stars are taken from the Catalogue of Nearby Stars by Gliese and Jahreiss (1991). The minimum space separation between the Sun and every star as well as the corresponding moment of time are calculated by two ways. Firstly, the straight line motions are considered. Secondly, the effect of the Galaxy potential is taken into account. The Galaxy model proposed by Kutuzov and Ossipkov (1989) is used. Twenty five stars approaching the Sun closer than two parsecs are selected. The effects of the uncertainties in the observational data are studied. The influence of the encounters to the Oort cloud is discussed.

Key words: Solar neighbourhood, Oort comet cloud

1. Introduction

The large sudden changes of the terrestrial climate could bear evidence of some possible cosmic catastrophes encountered by the Earth. One of the hypothetical reasons for such events is a close passage of a nearby star by the solar system. The encounters could initiate a shower of comets with small perihelia. A collision of the Earth with such a comet may lead to the catastrophic transformation of the climate. The cometary shower forming after a star's passage acts during $\sim 10^6$ years of the passage of the star. Thus it is of interest to trace the mutual trajectories of the nearby stars and the Sun during a short time (e.g. about 10^8 years) to the past and to the future.

2. Observational Data and Results

We consider the nearby stars from the Preliminary Version of the Third Catalogue of the Nearby Stars by Gliese and Jahreiss (1991). The stars with known heliocentric space velocities U, V, W are taken into account (1946 stars). Here the vector U is directed to the galactic center, V in the direction

Earth, Moon, and Planets **72**: 19-23, 1996.

of the galactic rotation, and W to the Northern Galactic Pole. The coordinates and velocities of the stars have been calculated in the galactocentric reference frame.

Firstly, we consider the straight line motions of every star with respect to the Sun. We found the shortest distance r_{min} from the Sun to this line and the corresponding moment of time t_{min}. The stars with $r_{min} < 2$ pc have been selected. The results for these 25 stars are presented in Table I. The values of r_{min} are given in 10^3 astronomical units; the times t_{min} are in 10^3 years. The Sun may have had encounters with three of these stars in the past and can have encounters with another 22 stars in the future.

A similar study was carried out by Revina (1988) who used the data from the previous version of the Catalogue of Nearby Stars (Gliese 1969). She found 25 stars (6 for the past and 19 for the future) having the close (less than 2 pc) encounters with the Sun. Ten stars from her list are the members of our sample. These stars are marked by an asterisk in Table I. Some of the disagreements of values r_{min} and t_{min} could be explained because the data is more precise in the new Catalogue. A similar study was also recently carried out by Matthews (1994). He has considered the stars from the solar neighbourhood with radius 5 pc. For a few stars he used slightly different initial conditions. Our results are in agreement with his results for the same stars.

We have taken into account the effect of the errors in the velocities U, V, W and in the parallaxes π to the values of r_{min} and t_{min}. A Monte Carlo method was applied to estimate the expectations and r.m.s. deviations of r_{min} and t_{min} for 25 stars mentioned above. We varied the additions to the input values U, V, W, and π by a Gaussian distribution with expectation equal to zero and dispersion $\sigma = 3$ km/s for the velocities and corresponding errors from the Catalogue for the parallaxes. The values of the expectations $\langle r_{min} \rangle$ and $\langle t_{min} \rangle$ as well as r.m.s. deviations σ_r and σ_t are also given in Table I.

Secondly, we consider the movements of the stars in the model Galaxy by Kutuzov and Ossipkov (1989). The distance of the Sun from the galactic center is adopted $R_0 = 8.23$ kpc and the height of the Sun upwards the galactic plane is $z_0 = 0.015$ kpc. The circular velocity at the solar distance R_0 is assumed $\Theta_0 = 226$ km/s. The components of the solar motion are $U_0 = +8$, $V_0 = +12$, $W_0 = +7$ km/s. We have integrated the equations of the motion of the Sun and of each star from 1946 stars with known space velocities during 10^8 years forwards and to the past. We neglected the interaction between the stars and the Sun, as well as the influence of the irregular forces. Corresponding values of r_{min} and t_{min} are presented in Table I too.

The two methods are in a good qualitative agreement: the same stars were selected by each of the methods. Also the less is the error of the parallax the

TABLE I
The results for the nearby stars encountering the Sun

N	Name	Lin.	fit	Effect	of errors	Tidal	field
		r_{min}	t_{min}	$r_{min} \pm \sigma_r$	$t_{min} \pm \sigma_t$	r_{min}	t_{min}
82	GJ 2005	154	33.0	156 ± 24	33.2 ± 2.3	154	33.0
305	NN	317	1780	1540 ± 1830	1630 ± 2840	384	1720
456	NN	75	1630	1290 ± 740	1600 ± 560	32	1600
528	Gl 120.1	280	-431	436 ± 216	-435 ± 47	282	-430
943*	Gl 208	341	-530	523 ± 261	-523 ± 83	337	-529
1160	Gl 271	375	985	840 ± 436	963 ± 214	386	990
1718*	Gl 411	291	19.9	291 ± 13	19.9 ± 0.7	291	19.9
1844*	Gl 445	197	43.7	199 ± 28	43.7 ± 1.7	197	43.7
1848	Gl 447	385	70.3	387 ± 43	69.8 ± 6.6	385	70.4
1927*	Gl 459.2	298	418	1290 ± 18000	1200 ± 13200	303	417
1971	Gl 473	59.6	7.5	59.6 ± 4.7	7.5 ± 0.1	59.9	7.5
1973	Gl 474	53.5	427	363 ± 211	452 ± 126	54.4	427
2077	NN	342	1060	2220 ± 9840	2560 ± 11000	373	1050
2290*	Gl 551	218	25.9	217 ± 16	25.6 ± 4.7	218	25.9
2317*	Gl 559	186	27.2	186 ± 17	27.2 ± 3.2	186	27.2
2778	Gl 682	390	64.3	392 ± 42	64.3 ± 3.7	390	64.3
2848*	Gl 699	238	9.8	238 ± 6	9.8 ± 0.3	238	9.8
2853	Gl 700.1	362	427	478 ± 239	435 ± 82	367	429
2891*	Gl 710	259	1030	853 ± 445	999 ± 275	279	1050
2959	Gl 729	393	134	392 ± 83	130 ± 34	393	134
3167*	Gl 783	372	38.2	374 ± 31	38.3 ± 2.3	372	38.2
3536	Gl 860	388	89.0	392 ± 54	88.6 ± 7.9	390	88.7
3706	NN	91	-515	421 ± 230	-523 ± 109	112	-517
3735	GJ 2157	286	427	436 ± 228	432 ± 68	260	425
3742*	Gl 905	195	36.3	196 ± 23	36.4 ± 1.4	195	36.3

better is the quantitative agreement. All $|t_{min}|$ values are less than $2 \cdot 10^6$ years. Therefore our forecast is valid during about 10^6 years.

The minimum separation during this interval will take place with the star 456 (r_{min} = 32,000 AU and $t_{min} = 1.6{\cdot}10^6$ years). However, as it can be seen from Table I, the uncertainties of $\langle r_{min} \rangle$ and $\langle t_{min} \rangle$ for this star are rather large (mainly due to a big error of the parallax). The most reliable star having a close approach to the Sun is the star 1971 (Gl 473). Corresponding values are $r_{min} \approx 60,000 AU$ and $t_{min} \approx 7,500$ years.

TABLE II
Estimations of influence from the stars to the Oort cloud

N	Name	$M_*, M_\odot$	R_a	R_0	r_{min}	t_{min}
82	GJ 2005	0.18	46	108	154	33.0
305	NN	6.5	276	108	384	1720
456	NN	0.32	11.6	20.5	32	1600
528	Gl 120.1	0.75	131	151	282	-430
943	Gl 208	0.47	137	200	337	-529
1160	Gl 271	2.4	234	152	386	990
1718	Gl 411	0.39	112	179	291	19.9
1844	Gl 445	0.27	67	130	197	43.7
1848	Gl 447	0.24	126	259	385	70.4
1927	Gl 459.2	0.70	138	165	303	417
1971	Gl 473	0.31	21.5	38.4	59.9	7.5
1973	Gl 474	4.0	36.2	18.2	54.4	427
2077	NN	7.0	271	102	373	1050
2290	Gl 551	0.21	69	149	218	25.9
2317	Gl 559	1.8	106	80	186	27.2
2778	Gl 682	0.29	136	254	390	64.3
2848	Gl 699	0.21	75	163	238	9.8
2853	Gl 700.1	1.4	200	167	367	429
2891	Gl 710	0.42	110	169	279	1050
2959	Gl 729	0.23	128	265	393	134
3167	Gl 783	1.0	187	185	372	38.2
3536	Gl 860	0.56	167	223	390	88.7
3706	NN	1.0	56	56	112	-517
3735	GJ 2157	0.78	122	138	260	425
3742	Gl 905	0.40	56	139	195	36.3

3. Discussion

It is interesting to estimate the radius R_a of the action sphere for the stars with respect to the Sun in the moment of the closest approach. The approximate estimation is as follows:

$$R_a = \frac{r_{min}}{1 + \sqrt{M_\odot / M_*}}, \qquad (1)$$

where $M_\odot$ is the solar mass and M_* the mass of the star. We could estimate the corresponding distances $R_0 = r_{min} - R_a$ from the Sun, where the force acting to a comet from the Sun is the same as from the star. The masses of stars and values of R_a and R_0 are given in Table II. The crude mass estimates are taken from Allen (1973). The values of r_{min} and t_{min} are calculated taking into account the galactic field and they are presented in Table II as well. The star 1973 (Gl 474) will give a maximum effect to the Oort cloud in the near future because its action will exceed the action from the Sun at $r \geq 18,000 AU$ in the direction to the star. The outer parts of the cloud may be essentially deformed by the tidal force from the star.

We note a surprising asymmetry of the numbers of stars encountering the Sun in the past (3 stars) and in the future (22 stars). This asymmetry disappears when the critical distance is increased.

This work uses the most reliable observational data for the nearby stars. Therefore the stars singled out are good candidates for further detailed study of space motions and coordinates.

4. Acknowledgements

The authors are grateful to Mr. Ourusoff for the beautiful computer facilities he provided and for the assistance with operating data.

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