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Dynamics of nearby multiple stars. The α Centauri system

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Abstract. The triple star system α Cen AB and Proxima Cen – the component C – is the nearest to the Sun. The study of its dynamics has shown that this system is probably not a chance one. The motion of the component C (Proxima) with respect to the centre of mass of the pair AB is hyperbolic with the probability $P = 1.0$. We observe, therefore, a slow passage of C close to the pair AB. We propose the hypothesis that this system is a part of a stellar moving group. We list the probable members of this group amongst the nearby stars. Amongst them we have the binaries Gliese 140.1 and 676, the triple system ADS 10288 (Gliese 649.1), and six single stars. The probability to find these stars by chance inside the velocity space cube with a side of 20 km s^{-1}around α Cen is equal to about 2%.

Key words: binaries: general – stars: α Cen – stellar dynamics – solar neighbourhood

1. Introduction

This work is a continuation of the study of the dynamics of nearby multiple stars. Our aim is to study the dynamics of the nearest visual triple star α Cen + Proxima: to estimate the probability of a gravitational connection between the components, to establish the possible dynamical state of the system, and to outline the character of motions by computer simulation. Such work has been carried out earlier for the Castor = ADS 6175 (Anosova et al. 1989a) and ADS 9909 (Anosova 1990). A review of results for four systems ADS 48, ADS 6175, α Cen, ADS 9909 has been given by Anosova & Orlov (1991).

Anosova (1990) has shown that the probability P that the triple system α Cen AB and Proxima Cen is a chance system given by $P = 1\text{–}7 \cdot 10^{-8}$. The expected number of such chance groups within 20 pc of the Sun is EX = 10^{-4}. When we studied the dynamical evolution of α Cen + Proxima system, we used the data collected from literature as well as the data placed at our disposal by Worley (1985).

2. Data

The triple system under study is a distance of about 1.3 pc from the Sun. This system is unique because of the possibility to obtain the individual spatial positions and velocities of the components. The compiled information from Gliese's Catalogue is given in Table 1. The initial conditions for the study of the dynamics of this triple have been chosen on the epoch T_0 = 1915.0 since a dense series of spectroscopic observations was carried out just near this time.

In order to determine relative positions in the plane of the sky (coordinates ρ and θ), as well as proper motions (dρ, ρdθ) for the pair AB we use the information received from Worley. His Catalogue WDS contains the 465 observations from 1690 to 1982. The treatment of observations has been carried out by the method described by Anosova et al. (1989b). In addition, the arc of the apparent ellipse has been fitted by a section of a straight line or a parabola. Using the values found for dρ and ρdθ, we calculate relative motions $\delta(\mu_\alpha)$ and $\delta(\mu_\delta)$ of the component B with respect to the component A. These quantities are given in Table 6.

The data for determining $\delta(\mu_\alpha)$ and $\delta(\mu_\delta)$ of C with respect to A are collected in Table 2. The last line of this table contains the average quantities of these values.

Parallaxes of A, B, C are presented in Table 3. Table 3 contains individual parallaxes of A, B, C; the last line presents the average values and r.m.s. deviations of these values.

Masses of the components of the system (see Table 4) have been taken from the literature and estimated independently using the following formulae (Martynov 1988):

$$\begin{aligned} \log M &= (6.76 - M_{\rm bol})/3.85 \quad \text{for } M_{\rm bol} > 7.5\,, \\ \log M &= (4.62 - M_{\rm bol})/10.03 \quad \text{for } M_{\rm bol} < 7.5\,. \end{aligned} \qquad (1)$$

A value of the absolute bolometric magnitude $M_{\rm bol}$ has been estimated using known color indexes $B-V$ and absolute magnitudes M_V (see Table 5).

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Table 1. Compiled observed data

Component	α_{1950}	δ_{1950}	V	Sp. type	μ_α (arcsec yr^{-1})	μ_δ (arcsec yr^{-1})	V_r (km s^{-1})
A	$14^h36^m11^s$	$-60°37.8'$	-0.0^m	G2 V	−3.61	+0.71	−22
B	–	–	+1.3	KO V	–	–	–
C	$14^h26^m19^s$	$-62°28.1'$	11.0	M5 V	−3.77	+0.79	−16

Table 2. Proper motions of components A, C

$(\mu_\alpha)_A$	$(\mu_\delta)_A$	$(\mu_\alpha)_C$	$(\mu_\delta)_C$	References
−3.606	+0.705	−3.75	+0.87	Jenkins (1952)
−3.608	+0.712	−3.77	+0.79	Gliese (1969)
−3.605	+0.705	−3.760	+0.785	Eggen (1979)

$\delta(\mu_\alpha)_{AC} = -0.154 \pm 0.010$
$\delta(\mu_\delta)_{AC} = +0.112 \pm 0.030$

Note : μ in arcsec yr^{-1}

Table 3. Parallaxes of the binary AB and component C

π_{AB}	π_C	References
$0''.751 \pm 0''.01^t$	$0''.762 \pm 0''.005^t$	Jenkins (1952)
0.747 ± 0.007^t	0.761 ± 0.005^t	Gliese (1969)
	0.764	Eggen (1978)
0.776 ± 0.012^d	0.758	Halliwell(1981)
0.755 ± 0.006^m	0.762^t	Halliwell (1981)
0.760 ± 0.03^d	–	Halliwell (1981)
0.751^d	–	Halliwell (1981)
0.745	0.764	Eggen (1979)

$\pi_{AB} = 0''.757 \pm 0''.006$; $\pi_C = 0''.761 \pm 0''.001$

Note: ^{d} dyn parallax; ^{t} tri. parallax; ^{m} mix. parallax

The mass of the component C when we use (1) is unreliable because it is significantly less than the lower limit of hydrogen burning star (about 0.08 $M_\odot$). The Proxima could not be a brown dwarf as this contradicts its spectral type dM5e (Gliese & Jahreiss 1991). We estimate therefore this value independently using a relation between masses of stars and their spectral types (see Straizys & Kuriline 1981). Then we obtain $M_C = (0.15 \pm 0.02)\ M_\odot$. This quantity does not agree with the previous one $M_C = (0.020 \pm 0.006)\ M_\odot$which had been calculated using the formula (1). We consider, therefore, both values of M_C. Table 6 shows the initial conditions for the triple star α Cen + Proxima Cen which we use for the study of the dynamics of this system. These values agree with the large amount of statistical material for proper motions and parallaxes of all components obtained for the period 1926–1971 and compiled by Kamper & Wesselink (1978).

We note that the uncertainty in the determination of the radial velocity of C is equal to 5 km s^{-1}. This fact influences strongly the results of the study of the dynamics of this triple system, which are, therefore, preliminary (see the Sect. 3). To have more confidence in the results, we need to obtain the radial velocity of C with higher accuracy.

Table 4. Masses of components in solar units $M_\odot$

M_A	M_B	M_C	References
1.05	0.9	–	Eggen (1978)
1.07	0.89	–	Halliwell (1981)
1.19 ± 0.14	0.90 ± 0.10	0.020 ± 0.006	This work
1.1 ± 0.1	0.90 ± 0.01	0.020 ± 0.006	Combined results

Table 5. Color indexes and absolute magnitudes

$(B-V)_A$	$(B-V)_B$	$(B-V)_C$	$(M_V)_A$	$(M_V)_B$	$(M_V)_C$
$+0.68^m$	$+0.88^m-$	$+1.90^m-$	4.34^m-	5.68^m-	$15.45^m \pm 0.08^m$
$+0.69^m$	$+0.90^m$	$+1.97^m$	4.70^m	5.72^m	–

Table 6. Initial conditions for the dynamics

Parameter x	$\langle x \rangle$	Parameter x	$\langle x \rangle$
ρ_{AB}	$17''.24 \pm 0''.03$	π_{AB}	$0''.757 \pm 0''.006$
θ_{AB}	$218°.54 \pm 0°.07$	π_C	$0''.761 \pm 0''.001$
ρ_{AC}	$7956'' \pm 6''$	$(V_r)_A$ km s^{-1}	-24.6 ± 0.3
θ_{AC}	$214°.3 \pm 0°.1$	$(V_r)_B$ km s^{-1}	-20.5 ± 0.6
$(\delta\mu_\alpha)_{AB}$	0.29 ± 0.02	$(V_r)_C$ km s^{-1}	-16 ± 5
$(\delta\mu_\delta)_{AB}$	0.58 ± 0.01	$M_A(M_\odot)$	1.1 ± 0.1
$(\delta\mu_\alpha)_{AC}$	-0.15 ± 0.01	$M_B(M_\odot)$	0.90 ± 0.01
$(\delta\mu_\delta)_{AC}$	0.11 ± 0.03	$M_C(M_\odot)$	(1)0.020 ± 0.006
$(\delta\mu_\delta)_{AC}$	0.11 ± 0.03	$M_C(M_\odot)$	(2)0.15 ± 0.02

Note: $\delta\mu$ arcsec yr^{-1}

3. Method and results

In the study of the dynamics of the triple star α Cen we use the following system of units:

distance r = 0.01 pc = 3.086 10^{16} cm,
mass $m = M_\odot$= 1.989 10^{33} g, (2)
time $t = 10^4$ yr = 3.156 10^{11} s.
Then the unit of a velocity v = 0.9778 km s−1,
the constant of gravitation $G = 6.674\ \ 10^{-8}$ cm^3 g^{-2} = 0.4498.

We use here the statistical method developed by Anosova (1986, 1988a,b) which takes into account uncertainties of the observational data: we consider variations of all data x_i (see Table 6) simultaneously in the intervals

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Table 7. Orbital elements of binaries AB and AB-C and the total energy of triple ABC

Parameter	Binary AB	Binary AB – C(1)[a]	Binary AB – C(2)[b]
Energy E_b	-18 ± 2	0.9 ± 0.9	$6. \pm 6.$
a	$0.013 \pm 0.001 = 18''$	-1.1 ± 0.2	-0.1 ± 0.2
e	0.963 ± 0.006	500 ± 500	500 ± 500
Period T	98 ± 14 yr	–	–
Catalogue AB	$a = 17.5''$	$e = 0.516$	$T = 80$ yr
Parameter	Triple ABC(1)[a]	Triple ABC(2)[b]	
Energy E	-17 ± 2	-11 ± 6	

Note : [a](1)$M_C = 0.020\,M_\odot$; [b](2)$M_C = 0.15\,M_\odot$

$$(X_i - 2\sigma_{X_i}, X_i + 2\sigma_{X_i})\ , i = 1, 2, \ldots, 17 \quad (3)$$

where

$$X_i = (x_1, x_2, \ldots, x_{17}) =$$
$$[\rho_{AB,AC}; \theta_{AB,AC}; (\delta\mu_{\alpha_{AB,AC}});$$
$$(\delta\mu_{\delta_{AB,AC}}); (V_r)_{A,B,C}; M_{A,B,C}; \pi_{A,B,C}]\ .$$

We assume the normal distribution of components of the vector X_i and carry out 1000 variations of x_i inside the interval (3) adopting the initial epoch $T_0 = 1915.0$.

For this initial epoch we calculate averages and r.m.s. deviations of the following values: the total energy E, and 'osculating' elements of both binaries AB and AB–C: the total energies E_b, semi-major axes a, eccentricities e and periods T. Table 7 presents results of our calculations for both quantities M_C.

We can formulate the following results of the statistical study of the dynamics of the triple system α Cen:

(1) total energy of this system is negative for all 1000 tests;

(2) The relative orbit of the components AB is elliptical with the probability $P = 1.0$. A comparison of calculated elements a, T, e of this orbit with those obtained from the observational data (Worley & Heintz 1983) shows a good agreement for the first two elements and a discrepancy in e.

In order to understand the reason of this discrepancy, we estimate the eccentricities of this orbit for different epochs T_0 using the positions from Worley (1985) for the epochs ± 10 years from T_0 and approximations of these short arcs by straight lines or parabolas (see Anosova et al. 1989b). Table 8 presents these results. Note that for different T_0 we use the same radial velocities of components because we have not the corresponding observational data. We can see that differences of e for different epochs T_0 are large – they change from 0.36 ± 0.18 to 0.963 ± 0.006; for Worley & Heintz's (1983) data, we have $e = 0.52$. We think that this disagreement of e may be connected with uncertainties of proper motions and radial velocities of the stars under study.

Note that the similar results we obtained earlier for the visual triple system Castor = ADS 6175 (Anosova et al .1989a): the eccentricity e of the inner close binary AB change from 0.28 ± 0.12 to 0.849 ± 0.017; from the data in the literature, we have the average quantity $\langle e \rangle = 0.417 \pm 0.040$.

(3) For external binary AB–C of system α Cen we obtain the hyperbolic passage of the component C past the binary AB with the probability $P = 1.0$. We may interpret this result in two ways:

Table 8. Functions $\langle e \rangle (T_0)$

T_0(yr)	$\langle e \rangle$	δ_e
1875.0	0.36	0.18
1915.0	0.963	0.006
1925.0	0.83	0.04
1935.0	0.71	0.03
1950.0	0.86	0.04
Catalogue AB	0.52	

I. really, the orbit of the external binary is an ellipse however we cannot obtain it confidently due to uncertainties of the observational data.

II. indeed, the orbit of the binary AB–C is hyperbolic.

But we can easily show that for an ellipsoidal distribution of space velocities of stars in the solar neighbourhood, the probability of chance approach of stars is small. We can suggest then the following hypothesis to explain the existence of the triple system α Cen of this phenomenon (see Anosova & Orlov 1991): the binary α AB Cen and Proxima belong to the same stellar moving group in the Sun's neighbourhood. Then such probability should be higher.

In order to check this hypothesis we examine the space velocities of stars from the Catalogue by Gliese & Jahreiss (1991). We find 12 stars with space velocities close to the average value for α Cen system: the differences of these velocities from that of α Cen are less then $10\,\mathrm{km\,s^{-1}}$; the directions of motions of nine of the stars are almost the same as that of α Cen; their trajectories with respect to α Cen are approximately straight lines.

Table 9 shows the observed data from the Gliese and Jahreiss for these stars: the equatorial coordinates $\alpha, \delta_{1950.0}$, trigonometric parallaxes π_t, space velocities U, V, W and spectral classes of stars.

Amongst 'satellites' of the α Cen system, we have six single stars, two visual binaries Gliese 140.1 AB and 676 AB in the Southern hemisphere and one triple star Gliese 649.1 (ADS 10288) ABC in the Northern one.

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Table 9. Satellites of α Cen system

No.	Gliese	α	δ	π_t	U (km s^{-1})	V (km s^{-1})	W (km s^{-1})	Sp. type
1	–	$0^h09^m12^s$	$-35°24.8'$	$0''.0322$	−25	4	9	F4 V
2	13	0 14 24	−52 55.9	0.0674	−29	4	5	G2 V
3	1021	0 43 25	−47 49.6	0.0481	−22	0	7	G5 IV
4	–	2 51 58	+61 19.1	–	−30	10	12	F4 V
5	140.1 A	3 21 43	−50 10.5	0.0510	−38	3	17	K5 V
5	140.1 B	3 21 42	−50 10.6	0.0510	−38	7	14	K
Proxima								
6	551	14 26 19	−62 28.1	0.7718	−25	−2	13	dM5 e
α Cen								
7	559 A	14 36 11	−60 37.8	0.7490	−32	4	14	G2 V
7	559 B	14 36 11	−60 37.8	0.7490	−26	−1	14	KO V
8	9554[a]	16 16 05	−50 02.1	0.0430	−33	−1	8	G8 III
9	649.1 AB	16 56 30	+47 26.3	0.0570	−26	−6	6	dK8
9	649.1 C	16 56 19	+47 26.0	0.0570	−25	−6	5	dK8
10	676 AB	17 26 15	−51 35.7	0.0833	−29	−5	12	MO
11	732.1	18 50 28	+52 54.6	0.0415	−28	−2	10	G9 IV

Note: [a] Wolley's Catalogue

We estimate the probability P that these stars are by chance inside a velocity space volume with the side 20 km s^{-1}: for the random ellipsoidal velocity distribution with moments $\langle U \rangle = -12.7$, $\langle V \rangle = -22.4$, $\langle W \rangle = -8.0$; $\sigma_U = 39.8$, $\sigma_V = 29.2$, $\sigma_W = 21.8$ km s^{-1}, we obtain the probability $P = 0.021$.

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