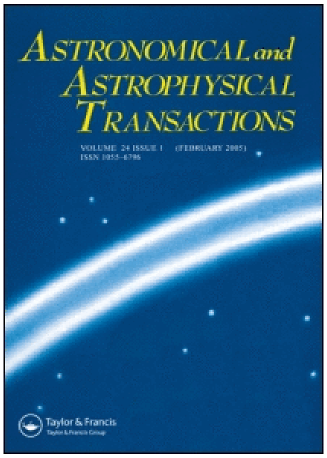

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Orbit evolution of the binary system 9 Cyg

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The composite spectrum star 9 Cyg is known as a spectroscopic and interferometric binary with an orbit period of 4.3 years. Speckle interferometric observations of the system were performed at the 6 m BTA telescope, while the spectra in the 3700–9200 A band were obtained with the 2 m telescope at Peak Terskol. A detailed analysis of the atmosphere of the system's main component was carried out using the collected data. An evolutionary status of 9 Cyg can be established from the collected data. The age of the system is approximately 400 million years, the brighter star being at the red giants transition stage, while the secondary is still passing the hydrogen burning stage close to the zero-age main sequence. A model is proposed of the orbit evolution, which explains its high eccentricity, $e = 0.79$.

Keywords: Spectroscopic and interferometric binary; Orbit; Evolution

Binary stars with highly eccentric orbits are interesting objects for the study of the origin and evolution of multiple stellar systems. The problem of the origin and conservation of highly eccentric orbits with strongly pronounced asynchronous rotation is at present also very interesting and unclear. 9 Cyg is an example of such a system. The peculiarities of the system are the high eccentricity of its orbit and the very large difference in rotation velocities of the components (component 1, 13 km/s, component 2, about 200 km/s). Griffin and Begs [1] found an orbital period of 4.303 years, an eccentricity of 0.7887 and masses of components $M_1 = 2.9M$ and $M_2 = 2.7M$.

Speckle measurements performed at the BTA telescope allowed the determination that the magnitude difference between the components is equal to $1^m.31$ in the band 6560/80 A [2].

Here we discuss the evolution status of the system and the possible formation scenario for pairs with highly eccentric orbits and fast rotation of the hot components using the specified atmospheric parameters of the components found from spectroscopic data collected with the 2 m telescope at Peak Terskol.

Comparison between the observed and calculated hydrogen lines profiles shows that the atmospheres of the components can be satisfactorily presented by the following parameters: $T_{\rm eff} = 5300$ K, $\log g = 2.80$ for component 1 and $T_{\rm eff} = 9400$ K, $\log g = 3.95$ for component 2 under the solar chemical composition (*i.e.* $z = 0.019$).

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The existing magnitude differences and effective atmosphere temperatures allow estimates of the components radii ratio. For measure Δm we have:

$$\Delta m = 2.5 \log \left(\frac{H_{\lambda,1} R_1^2}{H_{\lambda,2} R_2^2} \right)$$

whence we obtain the ratio R_1^2/R_2^2. The most probable value of this ratio is close to 16.0 and $R_1/R_2 = 4$. From this ratio and the effective temperatures we obtain the luminosity ratio:

$$\frac{L_1}{L_2} = \frac{T_1^4 R_1^2}{T_2^4 R_2^2} = 1.88.$$

The iron abundance in the atmosphere of the main component was estimated from equivalent widths of 48 measured Fe I lines and 23 Fe II lines. The lines of the secondary cannot be seen in the spectrum because of its high rotation velocity ($v \sin i = 200$ km/s). The calculations were performed using the KONTUR software [3] for models with $T_{\rm eff} = 5300$ K, $\log g = 2.80$ and different microturbulent velocities. Linear regressions

$$\log N(\mathrm{Fe}) = lgN(Fe)_0 + k \times W_\lambda$$

were found from the determined $\log N$(Fe) values at different V_t, thus allowing one to select a real V_t value in the atmosphere of the star. The corresponding regressions show that the microturbulent velocity in the atmosphere of 9 Cyg 1 is close to 2.47 km/s. The mean iron abundances in the atmosphere of the main component, obtained from Fe I and Fe II lines, are correspondingly:

$$\log N(\mathrm{FeI}) = 7.56 \pm 0.02, \log N(\mathrm{FeII}) = 7.49 \pm 0.07.$$

The iron abundance in the atmosphere of 9 Cyg 1 practically coincides with the solar value ($\log N(\mathrm{Fe}) = 7.50$) [4].

The abundances of C, N and O for 9 Cyg 1 were determined using the calculated synthetic spectra in the vicinities of CI, NI and OI lines with variations of corresponding abundances. For comparison the synthetic spectra of selected regions were calculated for the atmospheres of the Sun and Procion A (table 1). Their spectra were obtained at the same spectrograph as for 9 Cyg 1.

Line parameters were selected from the VALD list [5]. Spectral line broadening was considered in accordance with the method described in [6].

The luminosity ratio of the components and their total luminosity found from the visible magnitude and parallax ($\pi = 00641$, $L = 159L$ [7]) gives $L_1 = 103.8L$, $L_2 = 55.2L$. With these values of luminosities and corresponding effective temperatures the components fall onto the evolution isochrone [8] at $\log t = 8.60$ (t is evolution time in years) for stars with $z = 0.019$ and masses close to the estimates in [1]. Other combinations of luminosities and temperatures do not allow placing of both components at the same isochrone. Hence, the

Table 1. Parameters of models and contents of some elements in atmospheres of the Sun, Procion A and 9 Cyg 1.

Star	$T_{\rm eff}$, K	$\log g$	V_t, km/s	log$N$(C)	log$N$(N)	log$N$(O)	log$N$(Fe)
Sun	5770	4.40	1.00	8.46	7.78	8.96	7.43
Procion A	6530	3.96	2.20	8.57	8.15	9.06	7.44
9 Cyg 1	5300	2.80	2.47	8.28	8.21	8.74	7.53

components of 9 Cyg have an age of about 400×10^6 years, effective temperatures and gravity accelerations $T_{\rm eff} = 5300$ K, log $g = 2.80$ for component 1 and $T_{\rm eff} = 9400$ K, log $g = 3.95$ for component 2. The masses and log g values give the radii of the stars: $R_1 = 11.2R$ and $R_2 = 2.8R$. The hydrogen is totally burned out in the centre of the primary component. Its nucleus is in the stage of compression, while the envelope is expanding. The star is approaching the stage of helium burning in the nucleus, still remaining at the AGB. At the same time, the secondary star is in the middle of the hydrogen burning stage, being at the MS.

The data obtained by us on chemical abundance of the atmosphere 9 Cyg 1 are reasonably exact, proven true by comparison of our results for the contents of some elements for the Sun and Procion A with the data of other authors [9, 10, 4]. As can be seen in table 1, the CNO group abundances in the atmosphere of 9 Cyg 1 are significantly different from the solar CNO abundances. This difference can probably be explained by the atmospheric matter mixing with the matter from the region of nuclear reactions where almost all carbon and part of oxygen turn into nitrogen during the hydrogen burning in the CNO cycle. Both at the stage of evolution on the MS and on the red giant branch this mixing could be stimulated by the duplicity of the star [11]. However, such a process is possible only in the case of very short distances between the components and short rotation periods [12]. Therefore, we can make an assumption that there was a period in the history of 9 Cyg when the distance between the components and the orbital period were significantly shorter than today. The original radii of the components found for the masses $M_1 = 2.915M$ and $M_2 = 2.497M$ by interpolation of the data on the evolution tracks [8] are $R_1^0 = 1.89R$ and $R_2^0 = 1.75R$. This means that the radii of the components grew by a factor of 6 for 9 Cyg 1 and by a factor of 1.6 for 9 Cyg 2. If the radii increase occurred with conservation of the rotation moments of the stars and without a mass loss, the original rotation velocities should be $v \sin i = 77$ km/s and $v \sin i = 320$ km/s for the components 1 and 2, respectively. Here we suppose that the rotation axes of the stars are perpendicular to the orbit plane, the inclination angle is $i = 117°$ [1], and equatorial velocities are $V_1 = 86.5$ km/s and $V_2 = 359.5$ km/s. It is unclear how such a rotation velocity difference could arise. We conclude that 9 Cyg possesses the following peculiarities:

1. 400×10^6 years old system has very high eccentricity, $e = 0.7887$.
2. The collected data concerning the chemical composition of 9 Cyg 1 gives evidence of the matter mixing in component 1 during its evolution on the MS. Such mixing is possible in binaries with periods of 50 days or shorter, but not for periods longer than 1500 days [12] as in the case of 9 Cyg.
3. Observable high rotation velocity of the secondary (200 km/s) indicates that the rotation velocities of the components in the initial period of evolution were large enough.

High eccentricity of the orbit cannot be explained by the existence of the third body in the system because it is not detected either spectroscopically or interferometrically. In the same time, the above mentioned noticeable matter mixing could be an evidence for increased period of the orbit and its semi-major axis. Note that a white dwarf could be a third body in the system. It could remain after a supernova explosion provided an impulse for the orbit growth. Another possible scenario is a collision with another star or stellar system passed through the 9 Cyg system in the past.

Here we will consider a possible evolution scenario based on the proper peculiarity of the system. Suppose that in the early period the system was composed of components with the same rotation velocity. On reaching the zero age main sequence, the gravitational energy liberation is defined by the equation (see, for example, [13]):

$$E_{grav} \sim -\frac{0.6GM^2}{R}. \quad (1)$$

For the secondary at the zero age main sequence ($M_2^0 = 2.500M$, $R_2^0 = 1.75R$)

$$E_{grav2} = -8.124 \times 10^{48}\,\text{erg}.$$

The rotation energy found from the expression

$$E_{rot} = 0.2MR^2\omega^2, \tag{2}$$

for $V = 359.5\,\text{km/s}$ was, at the same moment, given by

$$E_{rot2} = 1.284 \times 10^{48}\,\text{erg}.$$

Using the virial theorem,

$$2(E_{therm} + E_{rot}) + E_{grav} = 0 \tag{3}$$

we can estimate the thermal energy of the secondary:

$$E_{therm2} = 2.778 \times 10^{48}\,\text{erg}.$$

Thus, during the contraction of the secondary star in the system, the ratio between the thermal and rotation energy is: $E_{rot2}/E_{therm2} = 0.462$.

It is reasonable to suppose that the same is true for the primary star. From the emitted gravitational energy during the contraction phase ($E_{grav1} = -10.227 \times 10^{48}$ erg) we can estimate the rotation energy of the primary component at the beginning of its evolution on the main sequence:

$$E_{rot1} = 1.622 \times 10^{48}\,\text{erg}.$$

This energy is substantially higher than energy for rotation velocity $V = 86.5\,\text{km/s}$ ($E_{rot1} = 0.087 \times 10^{48}$ erg). This velocity is determined for the first component on the line of zero age assuming conservation of the rotation moments of the stars.

From the first value of the rotation energy of the primary, its angular and linear velocities in the initial period were respectively: $\omega = 0.000284\,\text{s}^{-1}$ and $V = 374.0\,\text{km/s}$. These values are close to the rotation velocities of the secondary component. If we now suppose that at the beginning of the evolution the orbit of the system was close to circular with radius equal to the observed distance between the components in the present epoch in the periastron,

$$r = a(1 - e) = 70.24 \times 10^{11}\,\text{cm}, \tag{4}$$

then the energy of the orbital motion defined by the relation

$$E_{orb} = -\frac{GM_1M_2}{2a} \tag{5}$$

was $E^0_{orb} = -1.367 \times 10^{47}$ erg.

At the same time, the present orbital motion energy ($a = 334.5 \times 10^{11}$ cm [1]) is

$$E_{orb} = -0.287 \times 10^{47}\,\text{erg},$$

which is 1.080×10^{47} erg larger. It is possible to suppose that this energy was taken from the spin energy of the primary component decreased by 1.620×10^{48} erg during the evolution period. At the initial moment, the masses and distances between the components define the orbital period $P_{orb} = 50^d.5$. At the same time, the spin periods are $P_{rot} = 0^d.25$. Because the mass distribution in stars is not a point distribution, the gravitation creates tidal bulges on each of the components. These bulges move faster than the relative motion of the stars in the orbit, resulting in acceleration of their orbital motion. The acceleration energy is derived from the spin energy of the components. It is enough to use 7% of the spin energy of one component to transform the initially circular orbit into a highly elliptical one. The validity of the proposed mechanism of increasing periods and semi-major axes can be seen by the example of the Moon's rotation around the Earth [14, 15].

We finish with the following three conclusions. First, over 400×10^6 years a circular orbit can be changed into an elliptical orbit. Second, the initially small radius of the orbit and short period (less than 50 days) can cause mixing conditions in stars. Third, mass differences between components can lead to different radial mass distributions and, consequently, to different rates of rotation energy release. In this case, the spin velocity of the less massive star 9 Cyg 2 can be substantially higher than that of 9 Cyg 1.

References

[1] R.R. Griffin and D.W. Beggs, Mon. Not. R. Astron. Soc. **270** 409 (1994).
[2] M. Schoeller, I. Balega, Yu. Balega *et al.*, Pisma Astron. Zhurn. **24** 337 (1998).
[3] V.V. Leushin and G.P. Topilskaja, Astrofizika **22** 121 (1985).
[4] C.A. Prieto, M. Asplund, R.J.C. Lopez and D.L. Lambert, Astrophys. J. **576** 544 (2002).
[5] F. Kupka, N.E. Piskunov, T.A. Ryabchikova *et al.*, Astron. Astrophys. Suppl. **138** 119 (2005).
[6] Yu. Balega, V. Leushin and G. Waigelt, Astron. Zhurn. **82**(3) 1 (2005).
[7] C. Martin, F. Mignard, W.I. Hartkopf and H.A. McAlister, Astron. Astrophys. Suppl. **133** 149 (1998).
[8] L. Girardi, A. Bressan, G. Bertelli and C. Chiosi, Astron. Astrophys. Suppl. **141**, 371 (2000).
[9] N. Grevesse and A.J. Sauval, Astron. Astrophys. **347** 348 (1999).
[10] M. Asplund, A. Nordlund, R. Trampedach and R.E. Stein, Astron. Astrophys. **359** 743 (2000).
[11] V. Leushin, Kinematika i Fizika Nebesnich Tel. **5**(5) 47 (1989).
[12] Yu. Balega, V. Leushin and M. Kuznetsov, Astron. Zhurn. **82**(12) 1099 (2005).
[13] J.E. Tohline, Ann. Rev. Astron. Astrophys. **40** 349 (2002).
[14] O. Struve, B. Lynds and H. Pillans, *Elementary Astronomy* (Oxford University Press, New York, 1959).
[15] J. Chapront and M. Chapront-Touze, Celest. Mech. **66** 31 (1997).