THE BINARY-STAR HYPOTHESIS FOR THE NUCLEUS OF NGC 1514

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It is well known that the central star of the planetary nebula NGC 1514 ($\alpha_{50} = 4^h06^m\!.1$, $\delta_{50} = +30°39'$; $l^{II} = 165{\cdot}5$, $b^{II} = -15{\cdot}3$) differs from the other planetary nuclei by its high brightness (relative to the nebula) and late-type spectrum. The difference $B_* - B_n = 1^m\!.9$, and especially the A0-spectral type (Chopinet, 1963) are quite atypical for central stars. For these reasons we began a complex study of this object (Kohoutek, 1967; Kohoutek and Hekela, 1967) on the basis of the following sources of observational material:

(1) Palomar Sky-Survey prints (Schmidt-camera, Palomar Observatory);

(2) direct photographs in UBV system with the 2-m Schmidt-camera in Tautenburg (1962);

(3) photoelectric UBV photometry with the 65-cm reflector at Ondřejov (1964–65),

(4) spectrograms of the central star using the 122-cm reflector in Asiago (1965), and relatively infrequent observational data from the older literature.

Direct photographs show the nebula as almost circular and of dimensions 135″ × 121″ with a trace of an outer envelope (~175″), with a non-homogeneous brightness distribution and with condensations forming an irregular ring. Detailed investigations of isophotes (in the B region) disclosed two condensations at a 55° position angle symmetric to the central star (Figure 1). According to our concept of the morphology of planetary nebulae (Khromov and Kohoutek, 1968) the nebula may perhaps be classified as type 3 and the condensations may be considered to be the projection of a ring on the celestial sphere (the main axis is at a 145° position angle).

The distance of the nebula, calculated according to the statistical method from the mean surface brightness and from the angular diameter, was estimated as $r \simeq 480$ parsec; thus the linear diameter corresponds to $D = 0{\cdot}30$ parsec. The applied value of interstellar extinction, $A_V = 2{\cdot}0$ mag, was derived from photoelectric and spectrographic observations. The electron density $N_e = 290$ cm^{-3} ($N_e = 140$ cm^{-3}) of the principle and outer envelope, respectively, and hydrogen mass of the nebula $0{\cdot}10_\odot$ $(0{\cdot}07_\odot)$ indicate that this is a typical planetary nebula occurring rather at a late evolutionary stage.

For the central star let us first assume the spectral type to be A0. Then, however, the following contradictions with observational data appear:

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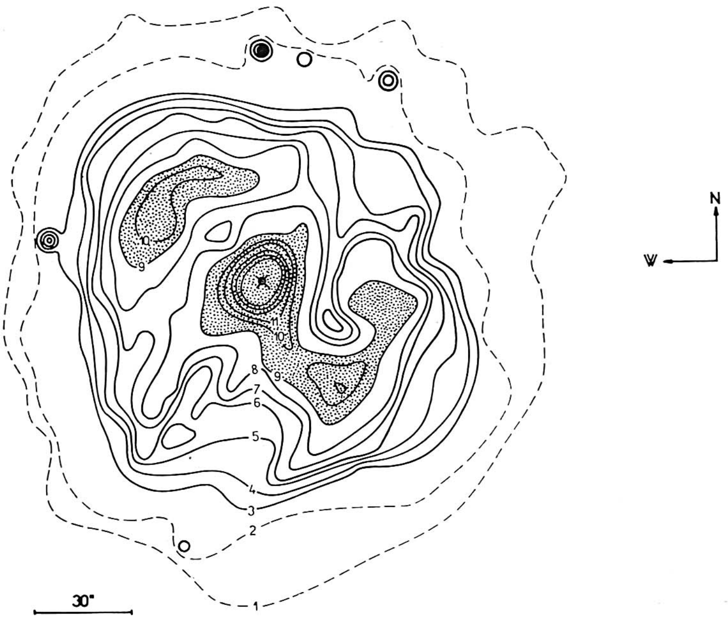

FIG. 1. *Isophotic contours of NGC 1514 in the B region* [*density scale: D = 0·03 (1), 0·06 (2), 0·10 (3), 0·14 (4), 0·18 (5), 0·22 (6), 0·27 (7), 0·33 (8), 0·40 (9), 0·50 (10), 0·60 (11)*].

(a) Relative to common stars of A0 type the central star of NGC 1514 shows an extraordinary U-B excess of about −0·4 mag, determined photoelectrically and spectroscopically.

(b) The theoretical Strömgren zone of completely ionized hydrogen is about five times smaller than the observed radius of the nebula.

(c) The temperature of the exciting star, derived from the intensity of the Hβ and HeII 4686 lines (Chopinet, 1963), is about six times higher than the corresponding value of the A0 spectral type.

We are convinced that the results mentioned are best accounted for by the existence of a second, much hotter component of the central star. A preliminary model of the nucleus of NGC 1514 gives the following parameters:

The physical double-star consists of

$$\text{A0 III (A-component)} + \text{blue sd (X-component)}:$$

$$\begin{array}{ll} M_{V,A} = -1 & M_{V,X} = +1{\cdot}2 \\ T_{*,A} = 10800\,°K & T_{*,X} = 60000\,°K \\ R_{*,A} = 4{\cdot}1\,R_\odot & R_{*,X} = 0{\cdot}45\,R_\odot . \end{array}$$

The luminosity class of the A-component was determined from the equivalent width of the Hγ line and from the electron density in the atmosphere of this star. The temperature of the X-component was estimated by means of the Harman-Seaton (1966) method from the magnitude of the central star and from the Hβ and He II 4686 intensities. There is no discrepancy between the dimension of the Strömgren zone of completely ionized hydrogen and the observed nebular radius at the temperature $T_{*,X} = 60000\,°K$; the optical thickness of the principle envelope is $\tau = 0{\cdot}085$.

The observed UV-excess is explained by the existence of the second component of the planetary nucleus. We can plot the dependence of the difference between the monochromatic magnitude of the continuum of the NGC 1514 central star and a common A0 star (in this case γ Tri) with the expression $1 + f(\lambda)$, where $f(\lambda)$ is the reddening function. The course of this dependence ought to be linear and its slope should be a measure of the interstellar extinction. The observed dependence $\Delta m[1 + f(\lambda)]$ (Figure 2) shows a drop at $\lambda = 3880$ Å, which, within observational errors,

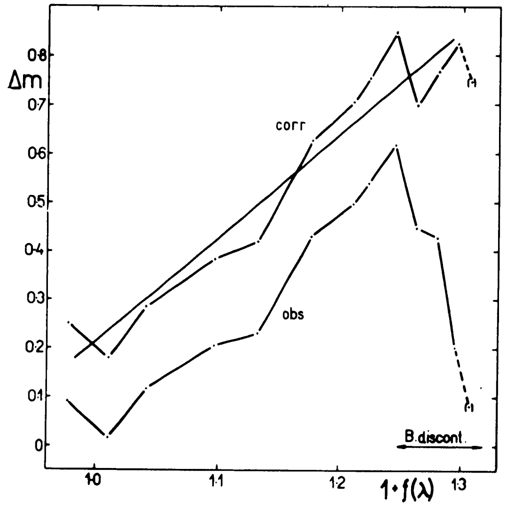

FIG. 2. *The dependence of difference Δm between the monochromatic magnitude of the continuum of NGC 1514 star and of γ Tri on the expression $1 + f(\lambda)$: obs – observed; corr – corrected by introducing the X-component.*

disappears by introducing the X-component of the planetary nucleus having the above parameters.

Figure 3 demonstrates the position of the stars of NGC 1514 on an H-R. diagram, specifically the position of the undivided nucleus (black circle) and that of the A and X-components. For comparison, the figure also contains the positions of 39 planetary nuclei (Harman and Seaton, 1966) and the evolutionary track of the nuclei of planetary nebulae determined by Seaton (1966).

An attempt at direct verification of the binary-star hypothesis has been made. First, the radial velocity of the central star was measured for six Balmer lines on three

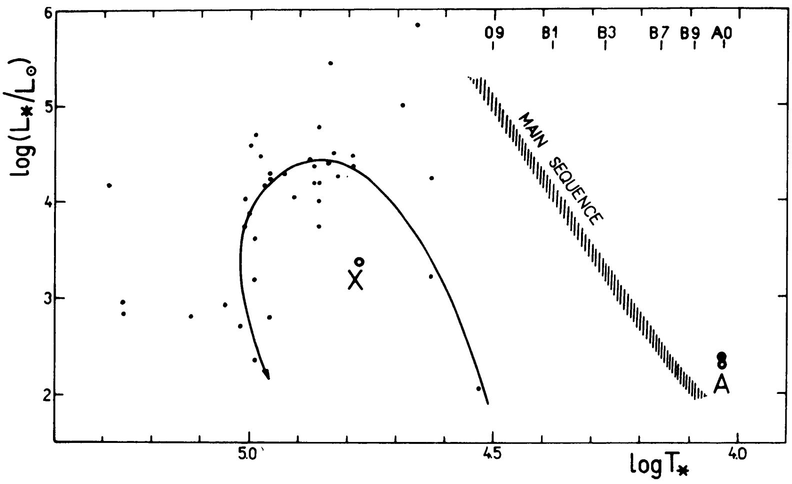

FIG. 3. *The position of NGC 1514 on the H-R. diagram: black circle = the undivided nucleus; A, X = the A- and X-components.*

Table 1

Date	V_{cor}
Jan. 8, 1954	+ 59·7 km/sec
Sep. 19, 1965	+ 86·5
Oct. 5, 1965	+ 66·2
Arithmetic mean	+ 70·8 km/sec

spectra made in Asiago (dispersion 74 Å/mm at Hγ) with the results given in Table 1, the mean error being about ±8 km/sec.

It is of interest that the mean V_{cor} of the central star agrees with the radial velocity of the nebula, reported by Chopinet (1963), +70·6 km/sec. This agreement is good evidence supporting strongly the hypothesis that the observed A-component is actually connected with the nebula and that it forms a physical pair with the hot subluminous star. The probability of a random occultation of two early-type stars would have been very small. The next paper deals with further measurements of the radial velocity of this central star which have been carried out in Asiago.

Photoelectric observations of the central star with the 65 cm reflector at Ondřejov have not revealed any light changes greater than the observational errors. Recently Lawrence *et al.* (1967) found evidence suggesting periodic oscillations of 855 and 138 sec with amplitudes of 0·01–0·02 mag. More detailed photoelectric and spectrographic observations of this object are very desirable and they are part of the program for our 2-m reflector at Ondřejov. Similarly, additional evidence on the possible binary nature of other central stars of planetary nebulae would be of great value, particularly for the study of the evolution of central stars.

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