SPECTROPHOTOMETRY OF RS OPHIUCHI
(NOVA OPHIUCHI NO. 3)*

BY O. C. WILSON AND E. G. WILLIAMS

ABSTRACT

From one good plate taken with the three-prism violet spectrograph on August 30, 1933, the apparent color temperature of RS Ophiuchi is found to be 4000° K.

Contours of the hydrogen emission bands have been determined from several plates covering the period August 16–September 11, 1933. On the assumption that the red sides of the bands present the true unmodified shapes, the following facts emerge:

a) The contours are roughly exponential in form. The earlier ones can be represented approximately by the formula \( I = e^{-(u/\mu_0)^n} \), where \( n = 1 + k(\mu_0/u) - k \) and \( k = 0.125 \). The value \( \mu_0 \) decreases rapidly with time at first, then more slowly, finally attaining a more or less constant value; \( k \) also decreases and may be considered to vanish for the later contours.

b) In addition to a sharp absorption component present on the short-wave-length sides of the band maxima in the early stages, there appears to be a general deficiency of intensity over the violet halves of the bands relative to that of the red halves. The supposition that this is due to the complete suppression of the continuous spectrum under the violet sides is not in entire agreement with the facts, but there may be complicating factors. This hypothesis would require a large velocity range among the atoms directly in front of the star, and leaves no room for the monochromatic hydrogen absorption components or for the sharp nebular lines. It is suggested that the latter arise in a quiescent shell around the star left over from its previous outburst.

The Balmer decrement has been obtained from two accordant plates, and is found to be appreciably faster than the mean of those found by Plaskett and by Berman for planetary and diffuse nebulae. The observed decrement is brought into good agreement with the latter by applying the differential factors necessary to reduce a true temperature of 35,000° to an apparent one of 4000°. From several spectrograms it appears that the ratio of the area of \( H\gamma \) to the intensity in the underlying continuous spectrum did not vary greatly between August 16 and September 2, 1933.

Zanstra's method gives a photo-electric temperature of 35,000°, calculated from the measures on plate V404, August 18. If this is a real measure of the temperature, it follows from the preceding paragraph that, while the star decreased in brightness by about two magnitudes from August 16 to September 2, its temperature remained constant. This conclusion would imply that the fading of the star was due to a shrinkage in the radiating surface.

From the measured intensity of the K line, with an approximate allowance for a probable stellar blend, a distance of 950 parsecs is deduced. This is shown to be fairly consistent with the recent results of Stebbins and Huffer on the assumption that the difference between the photo-electric and apparent temperatures is due to space reddening.

I. APPARENT COLOR TEMPERATURE

RS Ophiuchi has been classed as a nova since 1901, when it was discovered at Harvard that in 1898 the star increased to magnitude


† Fellow in Astronomy on the Commonwealth Fund.
7.7 from a normal brightness of around 11. Between 1898 and 1933, aside from a smaller maximum of about the ninth magnitude in 1900, the star appears to have undergone only minor fluctuations in brightness around its previous normal value. On August 15, 1933, Peltier announced a sudden increase to magnitude 6.4. Later reports indicate that the maximum occurred on August 12 at 4.3.²

During several months following the maximum a number of spectrograms were obtained by various observers at Mount Wilson. Among them were two, V404 and V405, taken with the three-prism violet spectrograph by Wilson on August 18 and 30, and intended primarily for spectrophotometric analysis. The spectrograph used can be rotated about the optic axis of the collimator; and since the star is south of the equator and the observations were made near the meridian, the slit was set in the N-S line in order to minimize the effect of atmospheric dispersion.

The spectrograms were made on Imperial Eclipse Soft plates with a 10-inch camera giving a dispersion of 38 Å/mm at $H\gamma$. Photometric standards consisting of ten continuous spectra of known ratios were impressed on the plate during the star exposure by means of an arrangement built into the spectrograph. At the conclusion of the exposure on the nova, several spectra of α Cygni, then at a small zenith distance, were also recorded on the same plate.

Figure 1a shows a microphotometer tracing of plate V404 on which the spectrum was widened by running the star back and forth along the slit. The emission bands are well exposed, but the underlying continuous spectrum is rather weak for accurate measurement over a long range. On V405 the star was held stationary, and the centers of the stronger bands are burned out. The continuous spectrum, however, is suitable for measurement from about 5000 Å to beyond $He$. Our color-temperature determination therefore rests entirely on this one spectrogram.

The method employed in deducing the color temperature is that developed by the Greenwich observers.³ Differences in intensity, expressed in magnitudes, between the continuous spectrum of the nova

³ Fully explained in Observations of the Colour Temperatures of Stars Made at the Royal Observatory, Greenwich (1932). In the subsequent calculations we have adopted the recently revised value, $\phi_0 = 1.0$, for the standard Ao star, as given in M.N., 94, 488, 1934.
Fig. 1.—Microphotometer tracings of RS Ophiuchi: (a) August 18, 1934; (b) qualitative sequence of changes in $H\gamma$. 
and that of a Cygni are plotted against the reciprocals of the corresponding wave-lengths. For spectra of the black-body type, the plotted points should lie on a straight line. The observations are represented by the crosses in Figure 2. The upper solid line drawn through the observed points is transformed into the lower one by applying corrections for differential atmospheric extinction and for angle between the atmospheric spectrum and the slit, the latter computed on the assumption that the $H\alpha$ image was kept on the slit during the exposure. This supposition is probably nearly correct, since the star, as seen in the telescope, was very red. In any event, the effect of the total correction is small.

The main uncertainty, and the probable source of most of the scatter in the observed points, lies in the difficulty of drawing in the continuous background on the tracing. The spectrum can best be characterized as "lumpy," and in some regions numerous emission bands overlap and undoubtedly produce an apparent continuous background which is considerably too high. This effect is especially conspicuous between $H\beta$ and $H\gamma$ and was allowed for as far as possible.
Using the slope of the lower solid line of Figure 2, we find $\phi_{RS} - \phi_{a\, Cyg} = 2.17$. The choice of $a$ Cygni as a comparison star was unfortunate, since the Greenwich observers have found its color temperature to be variable. Nevertheless, with $+0.30$ as a reasonable mean value of its gradient, corresponding to a temperature of $12,200^\circ$, we find $\phi_{RS} = 3.47$. This value gives $4140^\circ$ or, in round numbers, $4000^\circ \text{K}$ as the apparent color temperature of RS Ophiuchi on August 30, 1933.

Although this determination is not of high accuracy, it is undoubtedly of the right order, as may be seen from the dotted lines in Figure 2, corresponding to temperatures of $6000^\circ$ and $2000^\circ \text{K}$. Unless some large and unsuspected systematic error is present in our work, the color temperature of the star probably lies between these limits.

Dr. Joel Stebbins has kindly communicated to us the results of a set of photo-electric color determinations made by him at the 100-inch telescope on August 16, giving an integrated color corresponding to spectral type $gG_3$. This result includes the hydrogen emission bands; and when allowance is made for them, the indicated type becomes somewhat earlier. Although Stebbins' result is not in very close agreement with ours of two weeks later, it at least confirms the moderately low color temperature found for RS Ophiuchi.

II. CONTOURS OF HYDROGEN EMISSION BANDS

Contour measurements of nova emission bands are by no means numerous.\textsuperscript{4,5} Fortunately, several spectrograms besides the two already noted are available for this purpose. These plates are one-prism spectrograms taken at Mount Wilson and photometrically calibrated by means of a tube sensitizer. Their dispersions are of the same order as that given by the three-prism violet spectrograph. The measures were made as usual by carefully sketching in the assumed continuous background below the band and using it as the zero point for the band emission intensities. Here again the presence of other emission bands affects the location of the background and introduces uncertainties into the measures of the hydrogen bands themselves, particularly in the wings. Nevertheless, the results, on the whole, seem to be satisfactory.

Figure 1b shows several microphotometer tracings of $H\gamma$, illustrating qualitatively the course of events. $H\beta$ and $H\delta$ are, of course, similar to $H\gamma$ on each spectrogram. On the earlier plates the bands are asymmetrical. A sharp absorption line appears to the violet of the band center, and the intensity over the violet side as a whole is perhaps deficient as compared with the red. Later on, the sharp absorption component fades out and the asymmetry, while still present, becomes less marked. The bands then gradually approach symmetry and decrease considerably in width. These matters will now be discussed more precisely.

Owing to the fact that, on the earlier plates, the violet halves of the bands are affected by absorption, we restrict ourselves for the moment to the red sides. The first question is the relation between band width and wave-length. The contours of the red sides of the bands on plate $\gamma 19820$, taken on August 16, are plotted in Figure 3, the maximum intensity of each band being set equal to 100 and the widths expressed as velocities. The agreement between the three
bands is very good, and, in particular, there is no evidence of a pro-
geressive change in the order $\beta$, $\gamma$, $\delta$. On this plate the maximum in-
tensities of all the bands could be measured; but on $\gamma 19818$, taken 
the same night, $H\beta$ was too intense at the center for measurement. 
The values for the outer portions of $H\beta$ can, however, be fitted very 
nicely onto the contours given by $H\gamma$ and $H\delta$; and, when this is 
done, the band shapes given by the two plates of August 16 agree 
perfectly. The contours of the red sides of the hydrogen emission 
bands in RS Ophiuchi on this date are therefore known with con-
siderable accuracy.

Previous measures of nova band widths have been made by setting 
a micrometer wire as accurately as possible on the edges. Even at 
best, when the bands terminate sharply, there is some difficulty in 
knowing just what defines the "edge." This difficulty is enhanced 
by the considerable intensity gradient between successive bands and 
by psychological factors which probably vitiate the comparison of 
widths. Nevertheless, on the whole, the results indicate that band 
widths are proportional to wave-length.6

In the present instance the word "width" has little meaning in 
the foregoing sense, owing to the gradual tailing-off of the bands. But the evidence presented in Figure 3, which is typical of all our 
measures, shows that here, too, the structure of the bands is such 
that displacements are proportional to wave-length. This result is 
in keeping with, but does not necessarily establish, the hypothesis 
that the displacements are the result of radial motion.

The theoretical shapes of emission bands produced by expanding 
gaseous shells have lately been under investigation,4,7,8 so it is un-
doubtedly worth while to see what kind of expression will represent 
those of Figure 3. The forms shown immediately suggest some sort 
of exponential. Experimentation with the equation $I = e^{-(u/\omega)n}$ shows 
that it cannot be made to fit unless $n$ is a function of $u$ and that with

$$n = 1 + k \frac{u_0}{u} - k$$

7 B. P. Gerasomivič, Zs. f. A. p., 7, 335, 1933.
an acceptable approximation is obtained. The squares in Figure 3 were computed in this way, with \( k = 0.125 \). The value \( u_0 \) is of course the velocity for which the intensity is \( 1/e \) of its maximum value.

Chandrasekhar, whose results include those of Gerasimović, has published drawings of the contours to be expected if certain assumptions are fulfilled. None of these curves resemble, even remotely, our observed contours. Since we believe the observational results to be fairly reliable, we conclude that for some reason the theory, as thus far developed, does not apply to RS Ophiuchi.

We have also determined the contours on several other plates covering the entire interval from August 16 to September 11. On some of these spectrograms the central region of \( H\beta \) was overexposed, but experience with the two plates of August 16 indicates that the \( H\beta \) measures may be satisfactorily fitted onto those of the other bands. The results are shown best by plotting the mean shapes, as in Figure 4, the essential data for which are in Table I. For the plates following V404 the bands are so nearly symmetrical that half of the total width has been used in plotting.
The contours of September 2 and 11 coincide so closely that they cannot be separated on the scale of the drawing. Moreover, they are of the simple exponential type, i.e., \( k = 0 \). It has not been considered important to derive the value of \( k \) for August 18 and 30, since it is evident that there is a continuous transition in the contours.

The decelerating rate of change of the band shapes is noteworthy. The decrease in width (\( \mu_0 \)) from August 16 to 18 is 84 per cent of that during the twelve times longer interval August 18–September 11. Unfortunately, after September 11 it was possible to secure spectrograms of only rather small dispersion, but an inspection of plates of October 1 and 29 shows that on these dates \( H\beta \) had approximately

<table>
<thead>
<tr>
<th>Curve</th>
<th>Plate</th>
<th>Date</th>
<th>( \mu_0 )</th>
<th>( k )</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. ( \gamma_1 )</td>
<td>V404</td>
<td>Aug. 16</td>
<td>880</td>
<td>0.125</td>
</tr>
<tr>
<td>b ( \gamma_2 )</td>
<td>V406</td>
<td>Aug. 18</td>
<td>620</td>
<td>( \ldots )</td>
</tr>
<tr>
<td>c ( \gamma_3 )</td>
<td>V435</td>
<td>Aug. 30</td>
<td>440</td>
<td>( \ldots )</td>
</tr>
<tr>
<td>d</td>
<td>( \gamma_4 )</td>
<td>Sept. 2</td>
<td>310</td>
<td>0.000</td>
</tr>
<tr>
<td>e</td>
<td>( \gamma_5 )</td>
<td>Sept. 11</td>
<td>310</td>
<td>0.000</td>
</tr>
</tbody>
</table>

the same general appearance and width as on September 11. Thus it seems safe to say that the band widths decreased very rapidly for a time after maximum, the rate of decrease becoming gradually smaller until about September 1, and that for at least two months thereafter the changes in width, if any, were small.

The violet halves of the bands differ markedly from the red sides only on the plates of August 16 and 18. On plotting the violet contours derived from these spectrograms in the same way as for the red halves, one general fact emerges at once, namely, that, aside from the one point where the maxima of the three bands are made to coincide, the contour of \( H\beta \) is everywhere higher than that of \( H\gamma \), which, in turn, lies above that of \( H\delta \). Two interpretations are possible. Either, for a given intensity, the bands are successively narrower in the order \( \beta, \gamma, \delta \); or, for a given width, they are successively weaker in the same order. The second alternative appears more like-
ly in view of the good agreement found between the shapes of the red sides of the bands, on the reasonable supposition that the physical cause of the widening is the same in both cases.

If we are to adopt the second point of view, the increasing deficiency of intensity, in proceeding down the series, of the violet relative to the red portions of the bands must be accounted for. The appearance of the sharp absorption components on the bright bands suggests strongly that they are a true absorption phenomenon. If we now suppose, in addition, a general absorption effective over the entire violet sides of the bands, sufficient in amount to suppress more or less completely the light from the star's continuous spectrum in those frequencies, the result would be qualitatively similar to that observed. The reason for this conclusion is that the emission intens-

<table>
<thead>
<tr>
<th>Band</th>
<th>(a) Red Half</th>
<th>(b) Violet Half</th>
<th>(c) Reduced Red</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hβ</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Hγ</td>
<td>0.51</td>
<td>0.28</td>
<td>0.46</td>
</tr>
<tr>
<td>Hδ</td>
<td>0.10</td>
<td>0.04</td>
<td>0.07</td>
</tr>
</tbody>
</table>

sities in the bands decrease much more rapidly from β to δ than do the corresponding intensities in the continuous spectrum. Hence, if the sections of the continuous spectrum under the violet halves of Hβ and Hδ are removed by absorption, a greater relative difference between the two halves of the band will be introduced in the latter case than in the former.

It is possible to make a rough test of the validity of this hypothesis in the following way. The red and the violet halves of the bands on the two plates of August 16 were plotted separately on a true intensity scale, and the areas under them determined with a planimeter. The measured intensity in the continuous background under each band was then subtracted from the contour of the red side, yielding, what we may call for short, the reduced red contour. The reduced contours were sketched in, leaving the peak intensities unchanged. The mean relative areas resulting from this procedure, with β taken as unity in each case, are given in Table II.
If the difference between the red and the violet halves of the bands were due entirely to the suppression of the continuous spectrum under the latter, columns (b) and (c) of Table II should be identical. This should be true, moreover, whether or not the unmodified shapes of the two sides of the bands were the same. It is also to be noted that the discrepancy between (b) and (c) will be increased if it is supposed that only a part of the continuous spectrum below the violet sides is missing.

There seems to be no way of extending this argument. The measures of the August 16 plates agree in showing that, below the sharp discontinuity, the violet side of Hβ is wider and has a greater area than the red half. This in itself would break down the absorption explanation if the bands were intrinsically symmetrical. The widths and areas of the violet sides of Hγ and Hδ do not present this difficulty, however, and the close agreement between the values of Hγ:Hδ in columns (b) and (c) is to be noted. It is quite possible that blends interfere with the violet wing of Hβ, although there is no direct evidence of their presence.

In spite of all these uncertainties, we cannot escape the feeling that at least part of the asymmetry in the bands is produced by absorption in the manner presented above. If so, we must conclude that the velocity range of the absorbing atoms in the direct line of sight to the star is of the same order as the band half-width. In fact, if the bands are intrinsically symmetrical, the measures show that the underlying continuous spectrum may be completely removed out to a displacement from the band center corresponding to a velocity of the order of 2000 km/sec. without producing a depression in the apparent continuous spectrum on the tracing. This circumstance would be in good agreement with the fact that the observed contours are so widely different from the theoretical, flat-topped, square-sided ones to be expected from an expanding shell of atoms with no internal velocity range. To account for the necessary accumulation of atoms in the lower level of the Balmer series, the metastability of the 2S state of the hydrogen atom can possibly be invoked.

In conclusion, it is only proper to point out that this hypothesis leaves no room at all for the almost monochromatic absorption components of hydrogen or for the equally sharp bright nebular lines.
(see Fig. 1b). These clearly originate in regions where the velocity range of the atoms is very small. Possibly the star was surrounded by an outlying quiescent shell of gas produced by its previous outburst. We would then suppose that when the radiation of the present outburst first arrived at this shell the excitation would be mild enough for a while to leave an appreciable fraction of the hydrogen atoms in the second (and perhaps other) levels. Then as the full effect of the burst of ultra-violet quanta made itself felt, the hydrogen would become completely ionized, the sharp absorption components would disappear, and their place would be taken in due time by the almost equally sharp nebular lines. If this was indeed the case, the radius of the outlying shell was probably of the order of several light-days.

Only one fact seems to emerge, with moderate probability, from this welter of supposition and that is that the complete explanation of all the observations in a case like the present one is likely to be fairly complicated. In fact, clear, unambiguous conclusions about these matters are, thus far, notable chiefly for their rarity.

For obvious reasons, it is greatly to be regretted that we could not include measures of \( H\alpha \). Several plates of that region of the spectrum were available, but the band itself was invariably so badly overexposed, even when the continuous spectrum was very weak, that little or no reliance could be placed on the results. We have also determined on plate V404 the relative intensities of the bands in the 4500–4700 \( \text{Å} \) region. The difficulty here was the impossibility of measuring wave-lengths with sufficient accuracy to be certain of the identifications in this notoriously blended mass of \( Fe^+ \), \( Ti^+ \), etc. Without proper identifications, the intensities by themselves are of little value.

III. THE BALMER DECREMENT

Probably one of the most important sources of information for deducing the nature of the physical processes occurring in novae will ultimately be measures of the relative intensities of the emission lines. In the present case our efforts in this direction have been restricted to a determination of a portion of the Balmer decrement. Plates V404 and V405, for which the necessary corrections can be found, have been used for this purpose.
On plate V404 the asymmetry of the bands is still noticeable, although not marked. Therefore the decrement from this spectrogram, obtained in the usual way by measuring the areas under the band contours, must be considered as a mean for the two sides of the bands. The central parts of both $H\beta$ and $H\gamma$ are overexposed on the plate of August 30, V405, so that the same method of determining the decrement could not be used. Since, in this case, the bands are quite symmetrical, the following procedure was adopted. The bands were plotted with the intensities on a logarithmic scale, and a mean contour representing all of them as accurately as possible was drawn on tracing paper. The vertical displacement necessary to bring each contour into agreement with the mean then gave the relative intensity at once. Finally, these apparent intensities were corrected for atmospheric absorption and for the angle between the atmospheric spectrum and the slit, and reduced to true relative intensities by making use of the standard a Cygni spectra on each plate. The results are given in Table III and are shown graphically in Figure 5, together with the mean of the results of Plaskett\textsuperscript{9} and of Berman\textsuperscript{10} for several planetary and diffuse nebulae. Except for $H\beta$, the ratios from the two plates are in excellent agreement. Owing to the fact that the bands are still somewhat asymmetrical on V404, a rather steeper decrement is to be expected from this plate than from V405. This effect may partly account for the discordance in $H\beta$, but probably the fact that the band is overexposed on the later plate is more to blame.

$H\xi$ is undoubtedly measured too intense because of blending with $He \lambda 3888.6$. The value obtained for $H\eta$ is of low weight because of

\begin{table}[h]
\centering
\begin{tabular}{|l|c|c|}
\hline
Band & V404 & V405 \\
\hline
$H\beta$ & 471 & 326 \\
$H\gamma$ & 100 & 100 \\
$H\delta$ & 39 & 40 \\
\hline
\end{tabular}
\end{table}

\begin{table}[h]
\centering
\begin{tabular}{|l|c|c|}
\hline
Band & V404 & V405 \\
\hline
$He$ & 20 & 10 \\
$H\eta$ & 25 & (16) \\
\hline
\end{tabular}
\end{table}

\textsuperscript{10} L. Berman, \textit{Lick Obs. Bull.}, 15, 97 and 102, 1930.
the extreme faintness of the image on the plate. We consider it likely, however, that this band is stronger than would be judged by an extrapolation of the straight line drawn through $\beta$, $\gamma$, $\delta$, and $\epsilon$. $He\epsilon$ also may be measured a little too strong because of $He\lambda 3964.7$.

In respect to Figure 5 it should be remarked that the horizontal scale is such that from an origin on the right (not on the diagram) the distances to the points marked $\beta$, $\gamma$, etc., are proportional to $n^{1/3}$, where, starting with $\beta$, $n = 2, 3$, etc. The vertical scale of intensities is logarithmic. This method of plotting is convenient, since it leads to linear relations for the observed quantities. The figure shows that

the observed decrement for RS Ophiuchi is appreciably faster than the nebular values of Plaskett and Berman. Several investigations$^{11,12,13}$ of emission-line B-type stars have shown that in these objects the decrement is very similar to that of the nebulae. The evidence thus far collected indicates, therefore, that throughout the considerable range of excitation extending from early B stars to planetary and diffuse nebulae the Balmer decrement shows little or no variation.

Let us assume for the moment that the intrinsic decrement in the present case is also the same as this more or less standard value.

$^{11}$ O. Struve, Zs. f. A.p., 4, 177, 1932.
How, then, is the greater observed steepness to be accounted for? Probably the most obvious explanation is selective absorption or scattering, due either to matter collected relatively close to the star or distributed more or less uniformly along the line of sight. In the next section we derive, by Zanstra’s method, a photo-electric temperature for RS Ophiuchi of \(35,000^\circ\) K. If now we suppose that selective absorption or scattering is responsible for the change in apparent temperature from \(35,000^\circ\) to \(4,000^\circ\) K and apply the factors so derived to the observed Balmer decrement, we obtain the dotted line in Figure 5. Oddly enough, the slope of this line, which presumably represents the true decrement at the star, agrees remarkably well with the values of Berman and Plaskett, lying, in fact, between them.

**TABLE IV**

<table>
<thead>
<tr>
<th>Plate</th>
<th>Date</th>
<th>Ratio</th>
<th>Plate</th>
<th>Date</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>19818</td>
<td>1933, Aug. 16</td>
<td>8.3</td>
<td>19824</td>
<td>1933, Aug. 29</td>
<td>11.3:</td>
</tr>
<tr>
<td>19820</td>
<td>16</td>
<td>10.4</td>
<td>V405</td>
<td>30</td>
<td>8.5</td>
</tr>
<tr>
<td>V404</td>
<td>18</td>
<td>7.4</td>
<td>V409</td>
<td>31</td>
<td>13.6</td>
</tr>
<tr>
<td>19823</td>
<td>21</td>
<td>7.9</td>
<td>19837</td>
<td>Sept. 2</td>
<td>9.0:</td>
</tr>
</tbody>
</table>

Of course this agreement may be entirely fortuitous; but it is, at any rate, suggestive. The ideal way to investigate the effect of space reddening would be to measure accurately the relative intensities of emission lines belonging to some multiplet extending over a fairly long interval of wave-length. If, then, on comparison with theoretical or laboratory ratios, the higher frequency members were found to be systematically too weak, the space-reddening point of view would be considerably strengthened. Unfortunately, the spectrum of RS Ophiuchi provided us with no unblended multiplets suitable for this test.

Collecting all our band-intensity material, we can answer one other important question, namely, what is the relation between the total emission in the bands and the intensity of the underlying continuous spectrum as the star fades? The data in Table IV are self-explanatory.
The available plates are of varying degrees of quality for photometric purposes; yet, as a whole, they show that, over the interval covered, the total emission in \( H\gamma \) probably retained a constant ratio to the intensity of the continuous background at the same wavelength. Since the bands were becoming narrower during this interval, it follows that the continuous spectrum faded with respect to the peak intensities of the bands.

IV. THE PHOTO-ELECTRIC TEMPERATURE OF RS OPHIUCHI

The only mechanism thus far proposed for the production of bright hydrogen lines in nebular masses which permits a determination of the temperature of the exciting star is that due to Menzel\(^1\) and to Zanstra.\(^2\) Since the temperature computed by this method rests squarely on certain definite assumptions, we shall, in the present case, refer to it as "photo-electric" as a simple means of distinguishing it from other possible definitions of temperature. Zanstra’s development and applications of this scheme are too well known to require more than the briefest résumé here. To arrive at the temperature of the central star in a planetary nebula, he makes the following main assumptions:

1. The hydrogen atoms in the nebula are ionized photo-electrically by ultra-violet radiation from the central star, and the bright lines are produced when protons and electrons recombine.

2. The star radiates as a black body.

3. The stellar radiation to the violet of the limit of the Lyman series is completely absorbed by the nebula.

4. The whole system is in a steady state.

Starting with this foundation, Zanstra shows that the temperature of the star is that value of \( T \) satisfying the equation

\[
\int_{x_0}^{\infty} x^2(e^x - 1)^{-1} dx = \sum x^2(e^x - 1)^{-1} A_v,
\]

where \( x = h\nu/kT \), and \( x_0 \) is the value of \( x \) at the limit of the Lyman series. The observational quantities are the \( A_v \), defined\(^3\) for a case

\(^3\) C. S. Beals, M.N., 92, 677, 1932.
like the present one, where the supposed nebular mass cannot be seen separately from the star, by

$$A_v = \frac{\int I_\lambda d\lambda}{\int I_s}.$$ 

The integrals are simply the areas under the band contours, and $I_s$ is the intensity of the underlying continuous spectrum in the same units.

We have all the data needed to carry out a computation of this sort for our nova; the only question is one of justification. In the first place, assumption (4) is very definitely violated. RS Ophiuchi was in anything but a steady state during the time our plates were taken. Nevertheless, since it must be admitted at once that we are almost equally at sea as to whether any or all of the other assumptions are in accord with the facts, we may as well proceed on the hypothesis that the known failure of (4) is of no consequence. Since at best we can expect only order-of-magnitude accuracy, the use of one plate should suffice.

V404 was selected for this purpose, and the values of $A_v$ were computed from the measured intensities. To find $A_v$, it was assumed that $H\alpha$ would have had an apparent intensity six times that of $H\beta$. This figure was arrived at by extrapolating the straight line through the observed points of Figure 5. $A_v$ was added in twice to allow for higher members of the series. In passing, it may be noted that since Zanstra’s method is not very sensitive, any reasonable assumption as to the intensity of $H\alpha$ would have led to nearly the same result. Zanstra’s equation was then solved with the aid of his table for the integral, with the result $T = 35,000^\circ$ K for the photo-electric temperature of RS Ophiuchi on August 18, 1933.

Whether this figure has any close correspondence with the true temperature of the star must, of course, depend on how nearly the assumptions underlying the computations agree with the facts. Presumably, if it has any meaning at all, it will be in the nature of a lower limit, as is generally the case with applications of Zanstra’s scheme.
On the supposition that in this way we do obtain a measure of the star's temperature, one interesting conclusion may be drawn from the results presented at the end of the preceding section. It was shown there that the ratio of the area under $H\gamma$ to the intensity of the underlying continuous spectrum maintained a constant value from August 16 until September 2 at least. During this interval, therefore, the photo-electric temperature must also have remained constant. On the other hand, the apparent brightness of the star decreased during the same interval by about two magnitudes. Hence, if the photo-electric and true temperatures are comparable, or even run parallel, we conclude that the decreasing brightness of the star was due, not to a falling surface temperature, but to a shrinkage in the area of the radiating surface.

In this connection it is unfortunate that our material for the determination of apparent color temperature is limited to but one plate. A visual inspection of all available spectrograms leaves one, however, with the feeling that the intensity distribution in the continuous spectrum did not undergo any radical changes during the time covered by the observations. This conclusion is supported also by measurements of the relative intensities in the continuous spectrum at $H\beta$, $H\gamma$, and $H\delta$ on all available plates. While these ratios are necessarily of low weight, there is no indication of any progressive change with the time, a result in accord with the statements of the preceding paragraph.

The data presented here are reminiscent of one aspect of H. H. Plaskett's study of Z Andromedae. It will be recalled that he found the apparent color temperature of this star to be almost certainly too low to provide the excitation demanded by the observed line spectrum. His measures of the Balmer decrement do not, however, give any support to the hypothesis that the low color temperature is a result of space reddening. If anything, he finds a slower decrement than usual.

18 K. Bohlin, ibid., 252, 26, 1934.
19 Plaskett, op. cit., p. 119.
V. H AND K ABSORPTION LINES AND THE DISTANCE OF RS OPHIUCHI

The H and K lines of Ca II appear in absorption on several plates, but on only one, γ19819, August 16, can they be measured photometrically. This is an excellent plate for the purpose, and we feel that the intensities obtained from it are entitled to some weight. H is superimposed on the broad emission of He but is well separated from its absorption component. K is also on an emission band of moderate strength, presumably that of Ca II in the star. If these lines were due entirely to interstellar calcium, some idea of the distance of RS Ophiuchi might be obtained directly from their intensities, but the measured radial velocities indicate that this may not be the case.

Merrill has constructed a diagram based on all available calcium and sodium velocities, from which we find that for a star having the galactic co-ordinates of RS Ophiuchi (l = 348°, b = +8°) a calcium velocity (including the component of the solar motion) of about —10 km/sec. might be expected. Since the star is located not far from one of the null points of the galactic rotation hypothesis, this velocity is practically independent of distance.

The mean velocity for the H and K lines (including one accordant measure of D1 and D2 of Na) derived from several plates by Adams and Joy is almost exactly —30 km/sec. The reason for the discrepancy may well be that the stellar H and K emission bands are accompanied by absorption components similar to those of hydrogen for which Adams and Joy find a velocity of —60 km/sec. If this is the true explanation, the observed H and K absorption lines are blends, about three-fifths being due to interstellar calcium and the remainder to the stellar components. In addition, it must be remembered that there may be an abnormal density of Ca II atoms around the star which originated in its previous outburst.

Williams20 has recently published the results of a study of interstellar calcium line intensities in a number of B-type spectra. Using both H and K to arrive at the intensity of the latter as described in that work, and in the same units (wave-numbers) used there, we find: total absorption of K = 60. Assuming the blend explanation

for the anomalous velocity, we have 36 as the total absorption of the interstellar component.\textsuperscript{21}

In order to use this result in estimating the distance of the nova, the K-line intensities of the above-mentioned paper were plotted against the distances of the stars given in the recent work of Stebbins and Huffer\textsuperscript{22} on the colors of the B-type stars. Following a suggestion by Merrill, one correction was made to these distances, namely, the absolute magnitudes of the c stars were taken as $-5$ throughout. Out of eleven such cases the scatter was appreciably reduced in nine and only slightly increased in two. The final diagram gave a rather good linear correlation between K intensity and distance, which indicates for a K intensity of 36 a distance of 950 parsecs. If there were no space absorption, the corresponding absolute magnitude of RS Ophiuchi at maximum would be $-5.6$.

We have shown that the apparent color temperature of the star is 4,000° and that the photo-electric temperature is about 35,000°. These temperatures are about the same as those generally attributed to K- and O-type stars, respectively. For normal stars of these types Stebbins and Huffer give color indices of $+0.64$ and $-0.23$. Thus the measured color excess is, in round numbers, $+0.9$. When Rayleigh scattering alone is operative, the visual absorption is about equal to the color excess, so that the absolute magnitude at maximum becomes $-6.5$. Since there probably is, in addition, some non-selective space absorption, the absolute brightness at maximum exceeds this value.

If the whole intensity of 60 units for K is ascribed to interstellar calcium, we obtain a distance of 1600 parsecs, and a lower limit to the brightness of $-7.6$.

It remains for us to see whether the observed color can be sufficiently explained by space reddening. On page 243 of their paper, Stebbins and Huffer show, in Figure 5c, the color excess per thousand parsecs ($E/1000$) as a function of galactic longitude. Their observations are rather scanty in the region of the sky near RS Ophiuchi, but

\textsuperscript{21} It seems worth noting that on this plate the measured ratio of K to H is only about 1.1.

\textsuperscript{22} J. Stebbins and C. M. Huffer, \textit{Pub. Washburn Obs.}, 15, 217, 1934. Subsequent references to Stebbins and Huffer are to this paper.
from the diagram we may estimate that at galactic longitude $348^\circ$, $E/1000 = +0.7$. At a distance of 950 parsecs the star is, therefore, slightly too red for this coefficient, whereas if we adopt the value 1600 parsecs, the corresponding color excess, $+1.1$, is 0.2 magnitudes greater than the observed. Hence we can say that if we take the distance of the nova as being of the order of 1200 parsecs, its low color temperature may be entirely accounted for by space reddening.

In conclusion, the writers desire to state that the many shortcomings of this work are only too obvious to them. The only extenuation offered is the fact that studies of this nature are at present practically nonexistent. If it does nothing more, this paper may at least serve to emphasize once again the urgent need for careful and complete spectrophotometric investigations of future novae.

Carnegie Institution of Washington
Mount Wilson Observatory
July 1934