THE SPECTRUM OF THE NEBULOSITY SURROUNDING T TAURI*

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ABSTRACT

The spectrum of the nebulosity immediately surrounding T Tauri was observed by placing the spectrograph slit in various position angles through the star. The spectrum of the nebula consists of emission lines of [*O* II], [*S* II], and *H*. The amount of light of T Tauri scattered or reflected in the nebula seems to be small. The outline of the nebula obtained from measurements of the extension of the emission lines is in agreement with that found from direct photographs.

Three distinct nebulous areas have been observed in the vicinity of the irregular variable star T Tauri.[1] The first of these, NGC 1555, was discovered by J. R. Hind in 1852 and is one of the best examples of a variable nebula. It lies about 45″ to the west of T Tauri. Another small nebula was discovered by O. Struve in 1868, about 4′ to the west of the variable star. This object is catalogued as NGC 1554. The third nebula was discovered visually in 1890 by S. W. Burnham[2] with the 36-inch Lick refractor. He described it as follows: "This star [T Tauri] is placed within a very small condensed nebula. It is somewhat elongated in the direction 151°.7. A rough reading of the wires gave 4″.4 for the length of the nebula in this direction. It is less extended on the opposite side of the star or nucleus, with a shorter diameter of perhaps half of that measured." This observation was corroborated a few nights later by Barnard. The object was re-examined by Barnard in 1895, with the surprising result that the small, very definite nebula surrounding T Tauri had disappeared and was replaced by a very faint, indefinite nebulous glow. The last observation published by Barnard was made in 1897 with the Yerkes 40-inch refractor, when he saw a very small nebulous patch very close to the variable, at a distance of 1″ or 2″, in the direction of the elongation of Burnham's elliptical nebula of 1890.

Photographs taken by W. Baade at Mount Wilson[3] have revealed, in addition to Burnham's nebula, a knoblike protuberance from the photographic image of T Tauri in p.a. 190°. It is with the nebulous features discovered by Burnham and by Baade that the present paper deals. I am greatly indebted to Dr. Baade for permitting me to inspect his direct photographs of the nebulosities at T Tauri.

Observation of the spectra of the close nebulosities at T Tauri is rendered difficult by their faintness and proximity to the variable star, which, at the time that the present observations were made, was of visual magnitude 10. A telescope of long focal length is required, as well as good seeing and careful guiding. The first attempt to secure spectrograms of the nebulae was made at the Lick Observatory in 1947 with the 36-inch refractor. The results obtained were of low weight because of the impossibility of guiding with sufficient accuracy. The problem was taken up again in the winter of 1948–49 with the 82-inch reflector of the McDonald Observatory. On three nights of very good seeing, it was found possible to obtain six spectrograms of the nebulosity which were apparently free from contamination by light from T Tauri. The procedure followed was to place the

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[1] The early visual observations have been summarized by E. E. Barnard in *M.N.*, **55**, 442, 1895; **59**, 372, 1899. Photographic observations of NGC 1554 and 1555 have been described by H. D. Curtis (*Pub. A.S.P.*, **27**, 242, 1915), F. G. Pease (*Ap. J.*, **45**, 89, 1917), and C. O. Lampland (*Pub. A.S.P.*, **48**, 318, 1936).

[2] *M.N.*, **51**, 94, 1890; *Pub. Lick. Obs.*, **2**, 175, 1894.

[3] See *Ap. J.*, **102**, 171, Pl. XV, 1945.

slit of the Cassegrain spectrograph through the image of the star in various position angles and then hold the star fixed on the slit during the exposure by the aid of a cross-wire in the guiding eyepiece. The exposure times ranged from 10 to 85 minutes on Eastman II*a*-0 film. The *f*/1 Schmidt camera was used with both glass prisms (dispersion 150 A/mm at $H\gamma$) and quartz prisms (330 A/mm at $H\gamma$). Figure 1 shows five spectrograms taken with the latter combination. The third, fourth, and fifth spectrograms of Figure 1, all obtained with an exposure of 60 minutes, show immediately that emission lines extend from the star to distances of about 8″ in p.a. 151° and 190° and to considerably lesser distances in the other orientations.

The strongest emission line in the nebula is λ 3726, λ 3729 of [*O* II], followed by the [*S* II] pair at λ 4068 and λ 4076, and the hydrogen lines. There is no possibility that this spectrum arises simply from light of T Tauri scattered in the instrument or by poor guiding, for the following reasons: The strongest emission lines in the nebula, those of [*O* II] and [*S* II], are much weaker in the star than H and K of *Ca* II. In the spectrum of the star, the [*S* II] lines are weaker than $H\delta$; in the nebula, the opposite is the case. Neither the *Ca* II lines nor the continuous spectrum of the star shows any extension in p.a. 151° such as would be present if instrumentally scattered light were responsible for the nebular spectrum. Furthermore, the outline of the nebula, as defined by the extension of the [*O* II], [*S* II], and *H* lines (see below), is consistent with its shape and dimensions as observed on direct photographs.

There is no indication of the presence of the [*O* III] lines at λ 4959, λ 5006, although the definition of the spectrograms is poor in that region and the stellar continuum very strong. R. F. Sanford has observed [*O* I] λ 6300 in emission in the spectrum of the star.[4] Because of the serious astigmatism of the spectrograph in the red, no attempt was made at McDonald to discover whether this line is actually due to the nebula.

The extensions of four representative emission lines from the center of the star spectrum, as well as the width of the overexposed stellar continuum, were measured on three plates of 60 minutes' exposure obtained with the 330 A/mm dispersion. The results are contained in Table 1 and are plotted in polar form in Figure 2. In order to demonstrate the amount of agreement between such measurements on different spectrograms, a few measurements (indicated by open circles and squares) made on two comparable negatives of 150 A/mm dispersion are also plotted in Figure 2. The limits of extension of the nebular lines in Figure 1 have been connected by dashed lines. These lines have been added simply to aid the eye and are not based on any additional information. A heavy circle has been drawn through the points marking the extension of the stellar continuum, which show the amount of spreading of the overexposed star image at the wave length of each line.

The outline of the nebula obtained from the extension of the [*O* II], [*S* II], and *H* lines shows the elliptical figure extended in p.a. 151° and the displacement of the star along the major axis in p.a. 331°, seen by Burnham and Barnard. The "protuberance" in p.a. 190° discovered by Baade is likewise evident. The dimensions of the nebula measured on the spectrograms have not been corrected for seeing and guiding errors and hence are undoubtedly larger than the true values of the extension of the nebula out to the surface brightness specified by the photographic threshold of these particular spectrograms. The symmetrical extension of the K line of *Ca* II in all directions except p.a. 190° may be due entirely to atmospherically or instrumentally scattered light of T Tauri. The K line certainly does not behave as do the other emission lines. Its absence in p.a. 151° demonstrates that that part of the nebula scatters or reflects very little direct starlight. The extensions of the H and K lines in p.a. 190° are faint, but look real. Their observation depends entirely upon one spectrogram, however.

According to Burnham, "On the night of November 1st [1890], Mr. Keeler examined

[4] *Pub. A.S.P.*, **59**, 134, 1947.

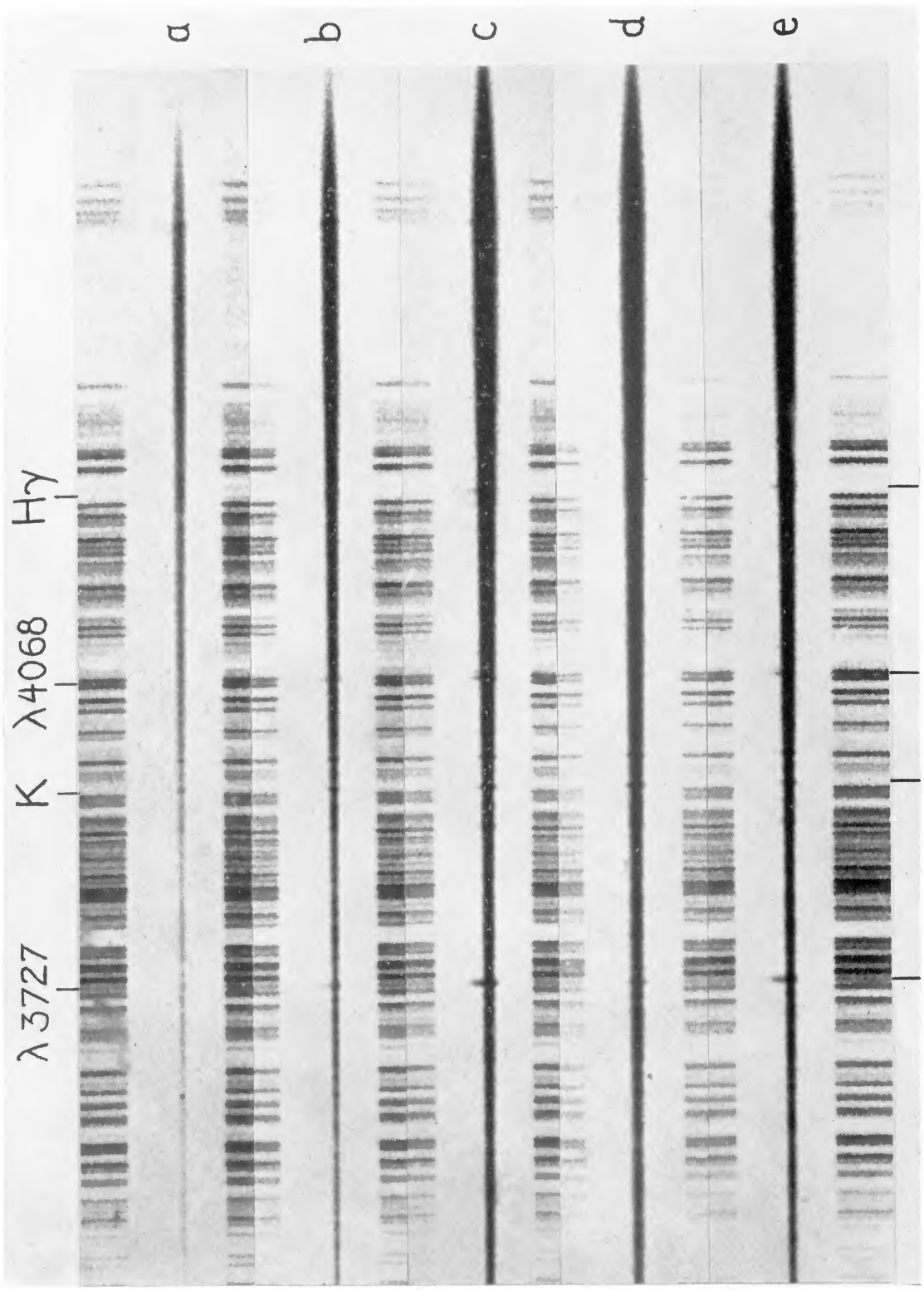

FIG. 1.—The spectrum of T Tauri and the surrounding nebulosity. These five spectrograms were obtained with quartz prisms and the $f/1$ Schmidt camera, giving a dispersion of 330 A/mm at $H\gamma$. The slit was placed through T Tauri in various position angles. The individual plate data are as follows: *a*, $Qf/1$ 11794, slit in p.a. 151°, exposure 1 minute; *b*, $Qf/1$ 11795, slit in p.a. 151°, exposure 10 minutes; *c*, $Qf/1$ 11796, slit in p.a. 151°, exposure 60 minutes; *d*, $Qf/1$ 11797, slit in p.a. 61°, exposure 60 minutes; *e*, $Qf/1$ 11813, slit in p.a. 190°, exposure 60 minutes. In each case the position angle quoted is that toward the top of the page. Note the growth of the nebular emission lines at λ 3727 and λ 4068, λ 4076 as the exposure time is increased in the first three spectrograms.

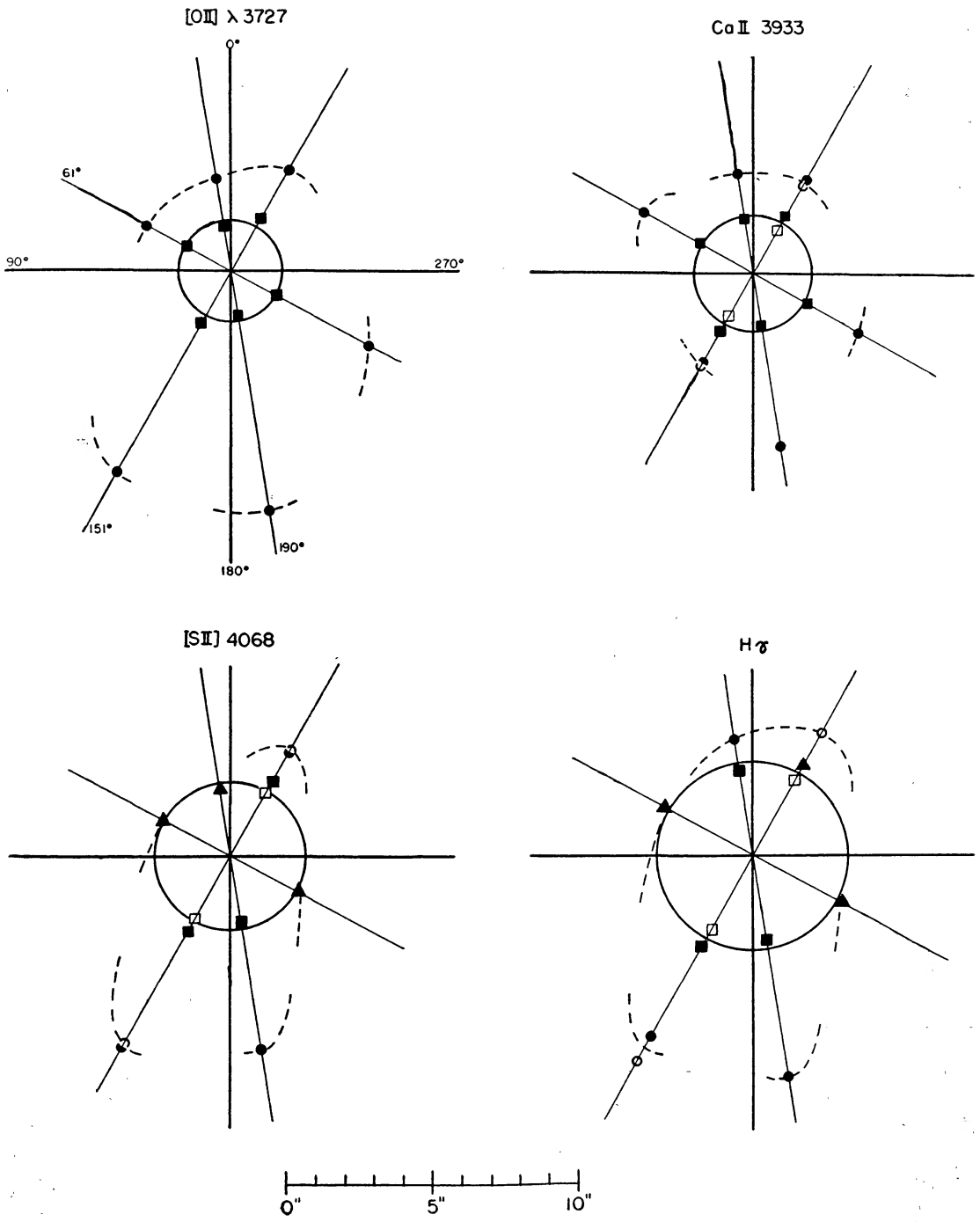

FIG. 2.—Polar diagram of the extension of the emission lines at T Tauri. Circles indicate the limit of extension of the emission lines. Squares represent the limit of extension of the overexposed continuous spectrum of T Tauri. Triangles indicate the limit of extension of the star spectrum when no extension of the emission lines was seen. Filled markings represent measures on Q $f/1$ spectrograms of exposure 60 minutes; open markings indicate measures on G $f/1$ negatives. The broken lines are intended to suggest the outline of the figure defined by the extension of the emission lines. The solid circles drawn through the squares and triangles represent the spread of the overexposed star image.

the nebula with the small spectroscope attached to the 36-inch telescope, and found that it was probably of the usual gaseous type, although on account of the extreme faintness of the nebula only the principal line at λ 5005 was visible."[2] The identification of the strongest bright line with [*O* III] λ 5006 is surprising, since that line has not been found on modern spectrograms of either star or nebula. No mention of this observation can be found in the original observing records of either Keeler or Burnham; hence it is not possible to say whether the identification is based on an actual measurement of wave length or is only the result of an estimate. Unless the spectrum of the nebula has changed, one would now be inclined to identify this line with *Hβ*. At any rate, this observation establishes Keeler as the discoverer of the emission nature of the spectrum of the nebula.

TABLE 1

EXTENSION OF THE EMISSION LINES AND THE STELLAR CONTINUOUS SPECTRUM FROM T TAURI, IN SECONDS OF ARC

	[*O* II] λλ 3726–29	*Ca* II λ 3933	[*S* II] λ 4068	*Hγ* λ 4340
	Q*f*/1 11796: Slit in p.a. 151°			
Half-width of stellar continuous spectrum....	2".10	2".30	2".92	3".62
Extension of emission line in p.a. 151°.....	7.97	3.53	7.56	7.23
Extension of emission line in p.a. 331°.....	4.03	3.78	4.11	.....
	Q*f*/1 11797: Slit in p.a. 61°			
Half-width of stellar continuous spectrum....	1.77	2.14	2.63	3.49
Extension of emission line in p.a. 61°.....	3.29	4.35	.....	.....
Extension of emission line in p.a. 241°.....	5.34	4.19	.....	.....
	Q*f*/1 11813: Slit in p.a. 190°			
Half-width of stellar continuous spectrum....	1.56	1.89	2.34	3.00
Extension of emission line in p.a. 190°.....	8.46	6.16	6.80	7.80
Extension of emission line in p.a. 10°.....	3.29	3.53	.....	4.11

The spectrum of the nebulosity immediately surrounding T Tauri resembles that of a gaseous nebula of low ionization: sufficient to produce O^+ but not O^{++}. The existence of an emission nebula apparently excited by a dG5 star is surprising. It may be that the primary mechanism responsible for the production of the nebular emission lines is not identical with that operating in ordinary gaseous nebulae but arises from the interaction of T Tauri with the dark nebula upon which it is seen projected. The close nebulosity at T Tauri is unique, so far as is known at the present time, among the emission-line objects associated with dark nebulae. However, very few other stars of this type have been adequately examined for such nebulosity.

I am indebted to Dr. G. P. Kuiper and Dr. O. Struve for placing the facilities of the Yerkes and McDonald observatories at my disposal, to Mr. J. F. Chappell of the Lick Observatory for preparing Figure 1, and to the National Research Council for the award of a Fellowship for 1948–49.