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SPECTROSCOPIC OBSERVATIONS OF CRL 2688

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ABSTRACT

Spectra of the visible objects at the position of the infrared source CRL 2688 indicate that these are nebulosities reflecting the light of an obscured F5 Ia star. Apart from this apparently normal spectrum, strong absorption features identified as molecular C_3 and emission lines identified as molecular C_2 and [S II] are observed. Our observations suggest that an F5 Ia star surrounded by a dense shell is at the position of the infrared source.

Subject headings: infrared sources — line identifications

I. INTRODUCTION

The unusual properties of CRL 2688 have been described by Ney (1975). The object is visible on the Palomar Observatory Sky Survey as a small egg-shaped nebulosity, but on the slit of the spectrograph the "Egg" is seen to be composed of two nonstellar objects of magnitudes ~13.5 and ~15 having characteristic dimensions ~3″.5 and a separation ~8″. Spectroscopic observations of the two components reveal that their spectra are identical but unusual. A description of the spectrum, our proposed line-identifications, and some properties of the object CRL 2688 indicated by our observations are given in this *Letter*.

II. OBSERVATIONS

Both conventional and image-tube spectra at dispersions of 78, 120, 165, and 240 Å mm^{-1} covering several spectral regions from 3700 to 7200 Å were obtained of both components of CRL 2688 with the f/1 spectrographs at the Cassegrain focus of the 1.83-m telescope at Victoria in 1974 between September 13 and October 23. The observations were made either by trailing a component along a slit 1″.6 wide × 60″ long or by the use of image slicers which accept light from an area 5″.4 × 3″.4 or 5″.3 × 2″.5. The image slicers have the advantage of acting like "moonlight eliminators" since the spectrum is widened without the use of a long slit. In the red region of the spectrum (5000–7000 Å) the typical spectral resolution was ~7 Å; in the blue region the highest resolution was ~1.5 Å.

Since the high polarization of the components is even apparent to the eye when viewed through a Polaroid filter, a pair of spectra were also obtained of the brighter component through a Polaroid filter with the plane of polarization (*a*) perpendicular and (*b*) parallel to the line joining the two objects. Altogether some 15 spectra of the brighter and seven of the fainter component were obtained. Two spectra in the red region were also obtained with a slit of width 3″.5 positioned between the two components, but it is not clear whether the resulting spectra are simply due to contamination of light (from the brighter component chiefly) or whether there is some intrinsic brightness not visible to the eye; in any event the spectra are identical to those of the brighter component.

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III. DESCRIPTION OF SPECTRA

All our observations indicate that the two components have similar if not identical spectra, and consequently it is suspected that they are simply reflecting the light from a hidden source. In what follows, the description of the spectra applies equally well to either component, although the lower quality of the spectra of the fainter object does not allow us to discuss possible small differences between the two components.

In the wavelength region 4100–5000 Å the spectrum is an excellent match to that of an F5 Ia star, but shortward of this wavelength the continuum appears to be depressed and many additional features are observed. These anomalous lines and some emission lines observed in the red region of the spectrum are listed in Tables 1 and 2. A spectrum of the brighter component obtained in the blue photographic region is shown with a spectrum of HD 10494, an F5 Ia standard, in Figure 1 (Plate L6).

a) Anomalous Absorption Lines

The presence of anomalous strong absorption features, particularly at ~4051 and 3992 Å, is very striking. To aid in identification, equivalent widths were measured at the positions of all these features in spectra of both the brighter component of CRL 2688 and HD 10494. The measured equivalent widths of CRL 2688 (col. [2] of Table 1) were then corrected for the contribution of any lines in the F5 Ia star, and normalized to the equivalent width of the 4051 Å feature to give a measure of the relative intensities, *I* (col. [3]), of the anomalous features. Due to the presence of strong mercury emission on the shortward wing of the 4051 Å feature, its true equivalent width had to be estimated and was taken to be twice that of the longward half of the line. This and the complexity of the underlying F5 Ia spectrum render the values of *I* as only approximate.

Although extensive searches were made, no reasonable identifications of these features with atomic lines could be found and so coincidences with molecular bands were looked for. The strongest feature at 4051 Å can

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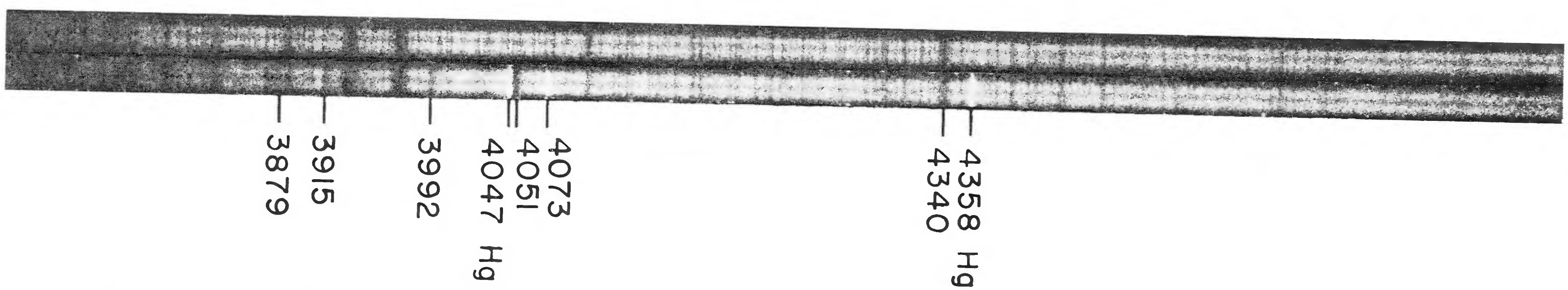

FIG. 1.—A spectrum of CRL 2688 (*lower*) in the blue region compared with that of HD 10494, an F5 Ia standard. The original dispersions were 78 Å mm^{-1}. Two strong mercury sky lines, the anomalous absorption features at 4051, 3992, 3915, and 3879 Å and the emission line at 4073 Å are marked. Note also that, in comparison with HD 10494, the continuum of CRL 2688 shortward of 4100 Å is depressed relative to the continuum at longer wavelengths.

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be tentatively identified with the strongest band of the famous "4050 Å group" now known to be due to molecular C_3, which is observed in emission in cometary spectra and in absorption in the spectra of carbon stars (e.g., Swings, McKellar, and Rao 1953). In columns (4) and (5) of Table 1 the laboratory wavelengths and intensities of the strongest band heads of C_3 observed by Gausset *et al.* (1956) are compared to the anomalous absorption features observed in CRL 2688. The agreement is very good if allowances are made for the [S II] emission blend at 4073 Å (see Table 2) and the strong absorption lines in the F5 Ia spectrum. We propose that all the anomalous absorption features and the depression of the continuum shortward of 4100 Å are due to absorption by the C_3 molecule—a phenomenon previously only observed in carbon stars.

The last column of Table 1 lists the difference in wavelength between the features observed in CRL 2688 and in the laboratory. The shift of the absorptions by ~0.7 Å to the red may be accounted for by the redward degradation of the C_3 bands. Swings, McKellar, and Rao (1953) observed a similar shift but of larger magnitude (~2.5 Å) in the spectra of carbon stars, and they noted that the C_3 emission observed in comets has a somewhat smaller shift presumably due to different band structure resulting from a difference in excitation temperature. The C_3 absorption features observed in the CRL 2688 spectra are at even shorter wavelengths, perhaps suggesting a still lower excitation temperature, although an intrinsic velocity shift could also be responsible. Until this question is resolved, it is not possible to determine whether the C_3 molecules are being accreted or being expelled from the star.

TABLE 1

ANOMALOUS ABSORPTION FEATURES

OBSERVED			STRONGEST C_3 BAND HEADS		
Wavelengths (Å)*	EW (Å)	*I*	Wavelength (Å)	*I*	Δλ (Å)
([S II] Emission)			4072.5	6	. . .
4050.6	3.9	10	4049.8	10	+.8
	5.5†	. . .	. . .	. . .	. . .
(Mn blend?)	. . .	. . .	4038.4	4	. . .
4018:	3.6	3	4018.3	4	. . .
3991.5	3.3	6	3990.8	8	+.7
3982.3	1.6	3	3983.1	4	−.8
(H)	. . .	. . .	3970.9	4	. . .
(H)	. . .	. . .	3965.9	3	. . .
3949.5	1.4	3	3949.1	4	+.4
(K)	. . .	. . .	3935.8	3	. . .
(K)	. . .	. . .	3925.9	3	. . .
3915.4	3.0	3	3914.5	3	+.9
3880:	2.1	3	3879.4	4	+.6
3872.2	2.0	3	3871.5	2	+.7

* The comments in parentheses indicate possible reasons why the bands observed in the laboratory were not observed here. The H and K lines both appear to be blends and to include the suggested bands.

† Due to strong mercury emission on the violet wing the true EW (5.5) Å) was estimated to be twice that of the longward half of the line. The observed value was 3.9 Å.

TABLE 2

EMISSION LINES OBSERVED

Measured λ (Å) (1)	Intensity (2)	Identification (3)	Comments (4)
4073.2	Moderate	λλ4068.6, 4076.2 [S II]	Width ~7 Å 4062 C_3 absorption superposed, 4077 Hg emission
5162	Moderate	λ5165.2 C_2	Width ~10 Å λ5172 Mg I absorption
5631	Weak	λ5635.5 C_2	Width ~15 Å
6562	Central emission:	λ6562.8 Hα	Absorption too weak for spectral type
6580	Very weak	λ6583.6 (N II)	Presence questionable
6715	Very weak	λ6717.0 (S II)	Presence questionable
6730	Very weak	λ6731.3 (S II)	Presence questionable

b) Emission Lines

The observed emission lines are listed in Table 2. In the visual region of the spectrum, emission lines of moderate strength are present at 5162, 5631 Å which we suggest as being the 0–0 and 0–1 bands of C_2. These features are broad and give the expected appearance of being degraded to the violet. However, the 1–0 Swan band of C_2 at 4737 Å is not present on our plates.

The emission line at 4073 Å nearly escaped our attention due to its close proximity to the mercury (sky) line at 4077 Å; but its width, measured position, and strength leave no doubt as to its identification as stellar (or nebular) in origin and probably due to the [S II] blend of 4068, 4076 Å. If the C_3 identification is correct, then the C_3 band at 4073 Å probably affects the width and position of the observed emission feature as well. The presence of the [S II] lines at 6717, 6731 Å is suspected on some of our spectra. Hα is present as a weak absorption and central emission is suspected. Aside from emissions at 5577, 5893, 6300 Å due to airglow, the only other line suspected is that of [N II], 6583 Å. No anomalous lines or molecular bands either in absorption or emission other than those listed in Tables 1 and 2 were detected.

If the places of origin of the F5 Ia spectrum and the anomalous lines are not the same, it is possible that their polarizations would be different and hence spectra obtained with cross polarizations could be different. The pair of spectra that we obtained in this way show no obvious differences, but they only cover the region 5400–6800 Å. This experiment should be repeated with higher resolution and extended to other wavelength regions.

c) Radial Velocity

The radial velocity of the "F5 Ia star" as measured from three photographic spectra of the blue region of the brighter component appears to be constant and equal to -44 ± 8 km s^{-1}. The "Egg" nebula associated with CRL 2688 is listed in Zwicky's catalog of compact galaxies (Zwicky 1971) as IV Zw 67, a pair of blue compact galaxies. The redshift of 3000 km s^{-1} for this object (presumably the brighter component) listed by Carozzi, Chamáraux, and Duflot (1973) appears to be in error.

IV. DISTANCE

Since we observe only reflected light from the stellar object, it is obviously impossible to obtain a spectroscopic distance modulus. If the observed radial velocity is due to differential galactic rotation, a kinematic distance of 9.5 kpc is derived. In the direction of CRL 2688 ($l = 80^\circ.2$, $b = -6^\circ.5$) such a distance would place the object almost outside the Galaxy. On the Palomar Sky Survey, nebulosity is seen over a large area near this position, and on the Ross-Calvert Atlas of the Milky Way a dust lane is apparent nearby. A more attractive hypothesis is to postulate that CRL 2688 is associated with this gas and dust in Cygnus and is in the association Cyg OB4 at a distance of ~1 kpc. At this distance, it would be ~110 pc below the galactic plane.

V. DISCUSSION

As already noted, the similarity of the spectra of the two components suggests that the two nebulous objects are simply reflecting the light from some centrally located star presumably coincident with the infrared source. A relatively opaque shell or disk surrounding the star obscures its light except for some which escapes to illuminate the visible nebulosities. The spectrum of the star is that of a normal F5 Ia supergiant with some anomalous features superposed, most notably [S II] and molecular C_2 emission and molecular C_3 absorption. According to Tsuji (1964), a low excitation temperature (~2500 K) and high abundance of C relative to N and O are required to form molecular C_2 and C_3. Other molecules such as CO, HCN, etc., would also be expected to form. Since the infrared observations indicate $T \lesssim 150$ K, it is possible that solid ices and grains may be present and that the molecules are formed by evaporation. The [S II] is presumably formed in a more extensive gaseous shell around the star, perhaps even in the visible nebulae.

There does not appear to be any definite spectroscopic evidence concerning the evolutionary status of the object. The strong [S II] is reminiscent of that observed in Herbig-Haro objects (e.g., Strom, Grasdalen, and Strom 1974), but parallels may also be drawn with the presumably much older object IRC+10216, a carbon star surrounded by a dust shell (e.g., Toombs *et al.* 1972). Both the infrared and optical properties of CRL 2688 are similar to those of IRC+10420 (Humphreys *et al.* 1973) and η Car. Although a rapid increase in brightness or the presence of shell lines has not been observed in CRL 2688, it is also tempting to relate it to objects of somewhat similar spectroscopic appearance, FU Ori (Herbig 1966) and V1057 Cyg (Grasdalen 1973). CRL 2688 does not appear to have changed much in brightness since 1930 when the Ross-Calvert Atlas plates were obtained, but further examination of old plate material would be worthwhile.

Some of the numerous observations which could be made to assist in the interpretation of this unusual object include monitoring the constancy of the light and spectrum, measurement of the radial velocities in the spectrum exhibited by the fainter nebulosity, spectroscopic observations of both components through polarizing filters, higher-resolution observations of the molecular bands, and searches for young objects nearby.

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REFERENCES

Carozzi, N., Chamáraux, P., and Duflot, R. 1974, *Astr. and Ap.*, **33**, 113.
Gausset, L., Herzberg, G., Lagerqvist, A., and Rosen, B. 1965, *Ap. J.*, **142**, 45.
Grasdalen, G. L. 1973, *Ap. J.*, **182**, 781.
Herbig, G. H. 1966, *Vistas in Astronomy*, **8**, 109.
Humphreys, R. M., Strecker, D. W., Murdock, T. L., and Low, F. J. 1972, *Ap. J.* (*Letters*), **179**, L49.
Ney, E. P. 1975, *Sky and Tel.*, **49**, 21.
Strom, S. E., Grasdalen, G. L., and Strom, K. M. 1974, *Ap. J.*, **191**, 111.
Swings, P., McKellar, A., and Rao, S. N. 1953, *M.N.R.A.S.*, **113**, 427.
Toombs, R. I., Becklin, E. E., Fogel, J. A., Law, S. K., Porter, F. C., and Westphal, J. A. 1972, *Ap. J.* (*Letters*), **173**, L71.
Tsuji, T. 1964, *Ann. Tokyo Astr. Obs.*, 2d series, **9**, 1.
Zwicky, F. 1971, *Catalogue of Selected Compact Galaxies and Post-Eruptive Galaxies* (Switzerland: F. Zwicky).

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