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THE LAW OF INTERSTELLAR EXTINCTION IN ORION

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SUMARIO

Hemos hecho observaciones fotométricas en el sistema (U, B, V, R, I, J, K) de una estrella sumamente enrojecida, de tipo temprano, NGC 2024 No. 1. Estas observaciones confirman que esta estrella realmente es de tipo temprano y que está metida en una nube interestelar.

Estos datos nuevos los hemos interpretado en términos de la ley interestelar de extinción, con el resultado de que en la dirección de NGC 2024 No. 1 el cociente entre absorción total y selectiva, $R = A_V/E_{B-V}$, es aproximadamente 5.5. Hemos encontrado que es imposible interpretar estos resultados observacionales suponiendo la existencia de una compañera de tipo tardío y una ley de extinción "normal". Nuestro resultado concuerda con el valor grande de R que se había encontrado en la región del Trapecio de la Nebulosa de Orión.

ABSTRACT

We have made U, B, V, R, I, J, K photometric observations on a highly reddened early-type star (NGC 2024 No. 1). These data confirm that the star is indeed of early type, imbedded in interstellar material.

These new data have been interpreted in terms of the interstellar extinction law, with the result that the ratio of total-to-selective absorption, $R = A_V/E_{B-V}$, is approximately 5.5 in this direction. We have found it impossible to account for the observational data by the assumption of a late-type companion and a "normal' extinction law. This new result accords with the very large value of R that has been found in the region of the Orion Trapezium.

Introduction

The law of interstellar extinction in the region of the Trapezium of the Constellation of Orion has been the subject of a number of investigations. Several of these, for example that of Sharpless (1952), have found that the extinction law in this region of the sky is abnormal, in the sense that the ratio of total visual absorption to selective absorption is about double that found elsewhere. More recently, Johnson and Borgman (1963) have reexamined this question, using new observational data in the infrared, and have concluded that the ratio of visual to selective absorption, $A_V/E_{B-V} = 7.4$, a value much higher than 3, which is usually accepted as "normal". Johnson and Borgman also showed that the ratio, $R = A_V/E_{B-V}$, is not constant, and that it may be higher than "normal" in the regions of space near very hot stars.

Unfortunately, the reddening of the Trapezium region is rather small and it is not possible to state unequivocally that the peculiar reddening law cannot be accounted for by a "normal" law combined with appropriate K-type companions for the reddened O-type stars. A short time ago, Dr. Guillermo Haro pointed out to us a star near ζ Orionis, which he thought might be an early-type star embedded in interstellar material and which appeared to be much redder than the Trapezium stars. This star, according to Haro, probably is the exciting star of the emission nebulosity NGC 2024. In this paper we present (U, B, V, R, I, J, K) data for this star and their interpretation in terms of the interstellar extinction law.

The observational data

The first observational datum for this star, which is identified as NGC 2024 No. 1 in Figure 1, that we obtained was a rather weakly exposed spectrogram taken with the nebular spectrograph on the 40-inch telescope of the University of Mexico. Examination of this spectrogram revealed that the star is a typical OB star on the Tonantzintla classification system and that there is no evidence in the blue region of a late-type spectrum.

The star was then placed on the multi-color photometric programs here and at the Lunar and Planetary Laboratory (University of Arizona) with the results that are given in Table 1. The star appears to be highly reddened and the (U, B, V) part of the photometry indicates that its spectral type is early B or O.

TABLE 1

The magnitude and colors of NGC 2024 No. 1

V	$(U-V)$	$(B-V)$	$(V-R)$	$(V-I)$	$(V-J)$	$(V-K)$
12.10	1.65	1.41	1.73	3.36	4.70	6.34

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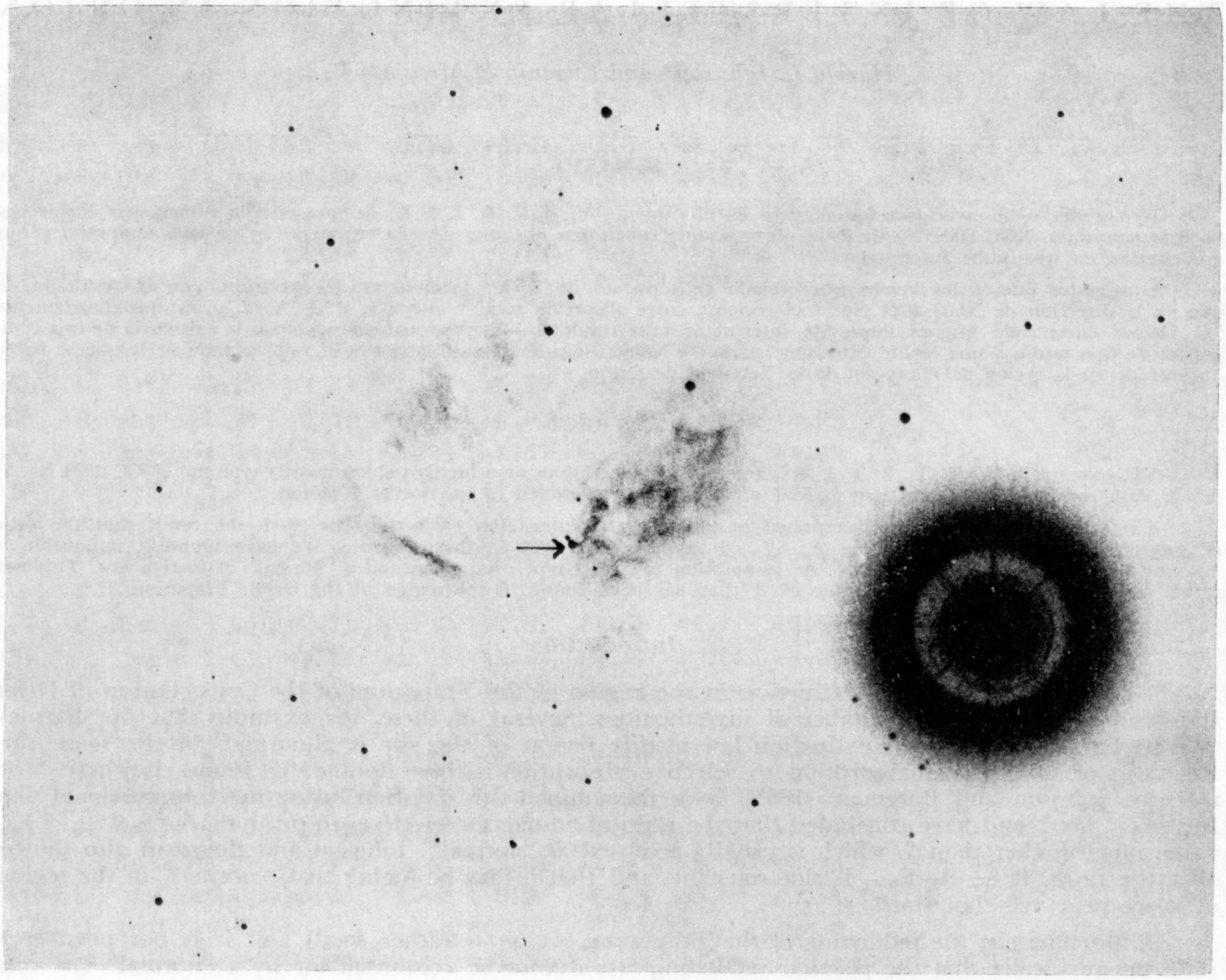

Figure 1.—*The identification chart for NGC 2024 No. 1. North is at the top and east to the left. The brightest star is ζ Ori. The photograph was taken in yellow light with the Tonantzintla Schmidt.*

The spectral type of NGC 2024 No. 1

While the evidence we have so far mentioned seems to be good, it is necessary to establish as firmly as possible that this star is in fact an early-type star that is highly reddened. Further evidence on this point is furnished by Figures 2 and 3. Figure 2 shows the spectral energy distribution curves for giant (or supergiant) stars ranging in spectral type from K0 to M5, plotted from the data given by Johnson (1964). Figure 3 shows the observed spectral energy distribution of NGC 2024 No. 1 (dotted curve) and the observed energy distribution of stars Nos. 9, 10, and 12 in the VI Cyg association. The latter stars have spectral types of O5f, O9Ia and B8Ia, respectively (Johnson and Borgman 1963). A comparison of the curve for NGC 2024 No. 1 with the other curves in Figure 2 and 3 shows plainly that it belongs in the class of reddened early-type stars, and not in the class of late-type stars. Compare particularly the curve for M5 in Figure 2 with the dotted curve in Figure 3; the sharp bend at the I point (near one micron) does not appear in NGC 2024 No. 1. Preliminary work on measures of Hγ intensities (see Johnson and Iriarte, 1958) indicates that the Hγ equivalent width of this star is small, in accord with its OB classification. We have, therefore, three independent data regarding the spectral type of the star: (1) The classification as OB from a spectrogram taken with the nebular spectrograph and the Hγ intensity. (2) The classification as early-B or O type from the (U, B, V) photometry; and (3) The classification as a reddened early-type star from the comparison of Figures 2 and 3.

This classification is strengthened further by the analysis shown in Table 2, in which are listed several stars having the spectral types in the second column and the observed (R–I) and (I–J) colors in the third and fourth columns. The ratio, (I–J) / (R–I), which is a measure of change in slope of the spectral energy curves of Figures 2 and 3 at the I filter, is given in the last column. Comparison of this ratio for the star under study with those of the other stars confirms in striking fashion the judgement from Figures 2 and 3 that the star is a highly-reddened early-type star.

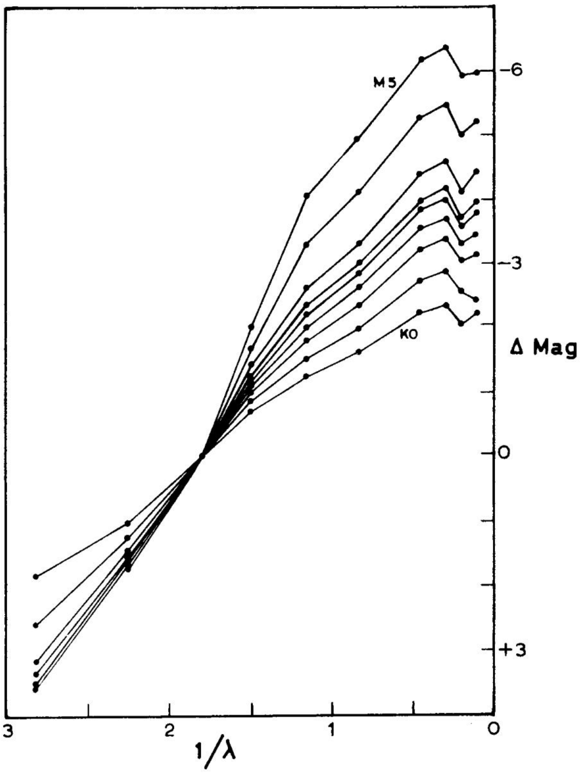

Figure 2.—*The spectral energy distribution curves for giants from K0 to M5.*

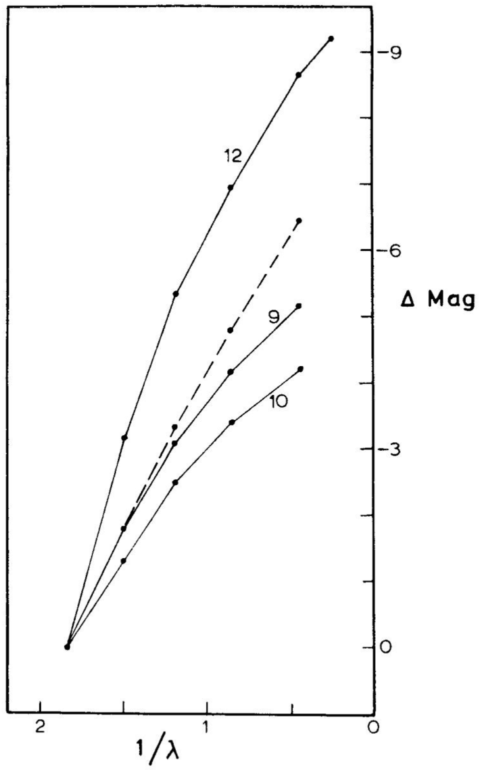

Figure 3.—*The spectral energy distribution curves for NGC 2024 No. 1 (dotted line) and for three highly reddened early type stars, Nos. 9, 10 and 12, in the VI Cygnus association.*

TABLE 2

Star	*Sp. Type*	*(R—I)*	*(I—J)*	*(I—J)* / *(R—I)*
χ Peg	M2 III	1.13	0.66	0.58
30 Psc	M3 III	1.41	0.83	0.59
α Her	M5 II	2.14	1.00	0.47
o Cet	M7e	3.40	1.52	0.45
VI Cyg No. 9	O5f	1.30	1.15	0.89
VI Cyg No. 10	O9Ia	1.20	0.86	0.72
VI Cyg No. 12	B8Ia	2.16	1.65	0.77
NGC 2024 No. 1	—	1.67	1.31	0.78

The law of interstellar extinction for NGC 2024 No. 1

Now that we have established that NGC 2024 No. 1 is a highly reddened early-type star, we can investigate the interstellar extinction in this direction by comparing the observed colors for this star with the intrinsic colors for early-type stars. This comparison is given in Table 3, where the first column lists the assumed spectral type of the comparison star (the intrinsic colors were taken from Johnson 1964). The other columns give the ratios of several color excesses to E_{B-V}. With the exception of the ratio, E_{U-V}/E_{B-V}, the color-excess ratios in Table 3 are remarkably independent of the assumed spectral type of star —even for a spectral type as late as F0 Ia. (A similar result would have been obtained for main-sequence stars, instead of supergiants).

TABLE 3

The reddening law for NGC 2024 No. 1

Comparison Star	$\frac{E_{U-V}}{E_{B-V}}$	$\frac{E_{B-V}}{E_{B-V}}$	$\frac{E_{V-R}}{E_{B-V}}$	$\frac{E_{V-I}}{E_{B-V}}$	$\frac{E_{V-J}}{E_{B-V}}$	$\frac{E_{V-K}}{E_{B-V}}$
O	1.80	1.00	1.15	2.25	3.18	4.31
B1 Ia	1.78	1.00	1.14	2.26	3.22	4.33
B3 Ia	1.72	1.00	1.17	2.29	3.26	4.38
B5 Ia	1.68	1.00	1.19	2.32	3.31	4.43
A2 Ia	1.38	1.00	1.23	2.38	3.36	4.50
F0 Ia	1.14	1.00	1.22	2.39	3.38	4.51

In all cases so far observed, the ratio E_{U-V}/E_{B-V} ranges from 1.70 to 1.90 (E_{U-B}/E_{B-V} from 0.70 to 0.90) and we can say, from the data in Table 3, that NGC 2024 No. 1 is not only an OB star, but that it is earlier than B5.

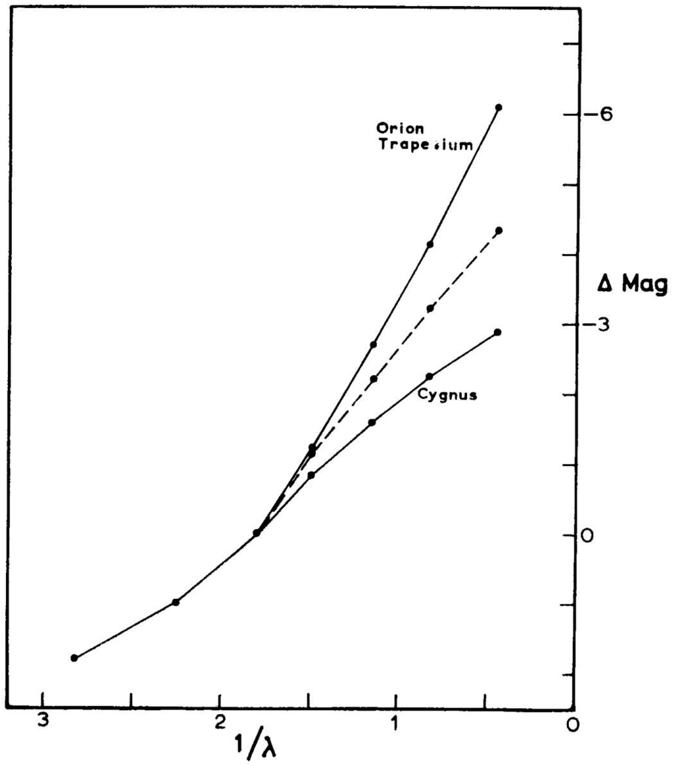

Figure 4.—*The interstellar extinction curves, normalized to E_{B-V} = 1.00, for three regions. The dotted line is the curve determined for NGC 2024 No. 1.*

The interstellar extintion law for this star is shown in Figure 4 (dotted line) along with those for the Trapezium and Cygnus (Johnson and Borgman 1963). It is evident that the ratio, $R = A_V/E_{B-V}$, exceeds 5 for this star. It is also of interest that, while the extinction curves for these three regions differ greatly in the infrared, they are virtually identical in the (U, B, V) region.

Conclusion

The U, B, V, R, I, J, K observations of NGC 2024 No. 1 have been interpreted in terms of interstellar extinction. The ratio of total-to-selective extinction, $R = A_V/E_{B-V}$, turns out to be greater than 5 (perhaps about 5.5); this is a strong determination because of the large color-excess, E_{B-V} = 1.7 mag. There is no evidence for the existence of a late-type companion either on the blue spectrogram or in the infrared photometry. Actual computations have shown that it is not possible, by any combination of a "normal" Cygnus extinction law, an early-type star, and any late-type star yet observed on the multicolor photometric program (Johnson 1964) to fit the observed data. We tried several K — and M-type giants and supergiants (including χ Cyg) and two carbon stars, DS Peg and T Lyr (data unpublished). The evidence that the interstellar extinction law in this direction differs from that in Cygnus (for example) is very strong and, in that sense, confirms the extreme deviation that has been found in the Orion Trapezium.

Assuming that NGC 2024 No. 1 is an O-type star of $M_v = -5.4$ at the distance of the Trapezium —distance modulus 8.1 mag. (Johnson and Iriarte, 1958), then we find the absorption to be $12.1 - 8.1 + 5.3 = 9.4$ mag. in excellent agreement with the obtained from the product of $R \times E_{B-V} = 5.5 \times 1.7 = 9.35$ mag.

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