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The interstellar extinction in the open clusters Tr 14, Tr 15, Tr 16/Cr 232 and Cr 228 in NGC 3372. New near-infrared photometry

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Summary. Near-infrared *JHKL* photometry of more than 200 stars, members of the open clusters Tr 14, Tr 15, Tr 16, Cr 228 and Cr 232 in the Carina Nebula are presented. From comparing these results with the available visual photometry and spectroscopy, it is found that, except in Tr 15, the intracluster reddening is characterized by a 'normal' extinction law at $\lambda > 0.5\,\mu$m but is highly anomalous and variable in the *U*- and *B*-bands. This behaviour may be explained by the presence of intracluster interstellar grains 'processed' by shock waves presumably associated with the explosive history of η Carinae. All clusters are found to be at the same distance from the Sun at $d = 2.4 \pm 0.2$ kpc or $V_0 - M_V = 11.9 \pm 0.2$. The total amount of reddening, though, differs significantly from cluster to cluster.

1 Introduction

NGC 3372, also known as the Great Carina Nebula, is a remarkable giant H II region which extends, in visible light, about 4 deg^2. Close to its brightest part, it contains the enigmatic nova-like object η Carinae. As described by Walborn (1973), the region is 'one of the most powerful laboratories available for investigating the early evolution of massive stars'. In fact, no less than eight stellar clusters exist within or very close to the nebula, four of which (those lying close to its centre) will be studied in detail in the present work. The region also shows the remainders of a vast molecular cloud as observed in CO-line emission (de Graauw *et al.* 1981) and OH and H_2CO absorption (Gardner, Dickel & Whiteoak 1973; Dickel & Wall 1974) and its radio continuum

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emission shows two main peaks (called Carina I and II), though with some complex structure (Retallack 1983 and references therein). Except for two visible dark lanes and obscuration patches, the radio emission agrees well with the optical luminosity maxima. From the study of the far-infrared maps of the region, Harvey, Hoffmann & Campbell (1979) suggested that the radio peaks represented ionization fronts at the boundaries of nearby dense clouds whose heated dust particles gave origin to the observed far-infrared emission with the hotter stars in the clusters Tr 14, Tr 15 and Tr 16 providing enough ionization and heating energy. Ghosh *et al.* (1988) have recently made maps at longer wavelengths with essentially the same results. In particular, Harvey *et al.* (1979) concluded that the dust in Car II (the southernmost peak) must be optically thin and that the observed high gas-to-dust ratio was probably due to destruction and evaporation of dust particles *in situ*.

The stellar contents of NGC 3372 have been extensively studied at visible wavelengths in the last 15 yr. Feinstein (1969) initiated a long and extensive visual photometric study of the stars in the clusters Tr 14 and Tr 16/Cr 232 (Feinstein, Marraco & Muzzio 1973; Feinstein 1982 and references therein), close to Car I and Car II respectively; Tr 15 (Feinstein, FitzGerald & Moffat 1980) located some 50 arcmin to the north and Cr 228, a 'loose' early-type star cluster in the southern part of the nebula (Feinstein, Marraco & Forte 1976). Walborn (1982a and references therein), Levato & Malaroda (1981, 1982) and Levato, García & Morrel (1987, private communication) have provided two-dimensional spectral classification of a large number of stars in the clusters.

The spectroscopic and photometric distance to these clusters has been determined to be in the range 2.3–2.8 kpc, though there is a long-standing controversy over the extinction properties of the interstellar material in the direction of the clusters (e.g. Turner & Moffat 1980). This has been centred on the various values of the total to selective extinction ratio $R = A_V/E(B-V)$ determined by several authors. The importance of such a controversy lies not only in the need for a reliable extinction law which would enable accurate determination of some physical parameters and distances to the clusters but also in the need for a better understanding of the properties of the interstellar material under the apparently extreme conditions prevalent in this region. This type of studies in Carina made by several authors (see Herbst 1976 and references therein) have yielded a large range of values of R, from a 'canonical' value of 3.2 (Turner & Moffat 1980) to 5 (Herbst 1976). Thé *et al.* (1980b) and Thé & Groot (1983) obtained near-infrared photometry of 29 stars in these clusters and concluded that higher than normal values of R are typical in this region. Turner & Moffat (1980) considered that the deviations from the normal extinction law reported previously were the result of misinterpreting infrared excesses and analyses of data for non-member stars. This view was partially supported by Tapia (1981) who argued that Thé *et al.*'s sample could not be representative as it contained a large fraction of supergiant and emission-line stars. Furthermore, Tapia (1981) found a normal value of the ratio $E(J-H)/E(H-K)$ when observing highly reddened background stars in the direction of these clusters. Very recently, Smith (1987) studied the brightest ($K \geqslant 9.7$) stars in an area of 18×18 arcmin^2 centred in the mid-point between Tr 14 and Tr 16. Smith's results will be compared in detail with those of the present work in Section 5.

High values of R are not uncommon in the direction of stars within dense molecular clouds, such as in Orion (e.g. Breger, Gehrz & Hackwell 1981) and Ophiuchus (e.g. Chini 1981) though, as will be seen in Section 4, these regions (unlike NGC 3372) have large densities of dust and molecular material and star formation is still occurring. In these regions, visual polarimetric observations also yield larger than normal values of the wavelength of maximum polarization λ_{max} which are normally accompanied by larger than normal values of R. These results are interpreted in terms of a shift in the grain size distribution toward larger grains due to selective destruction of the smaller grains by ultraviolet emission, among other causes proposed.

In order to investigate further the nature of the interstellar reddening in the direction of the clusters in NGC 3372 in the near-infrared and, in an unbiased way, as part of a long-term project of near-infrared studies of young clusters with evidence of anomalous extinction (*cf.* Tapia *et al.* 1984), we herewith report the results of *JHK* and sometimes *L*-band photometry of more than 200 stars located within the limits of such clusters and compare them with the available visual photometry and spectroscopy. The observations are described in Section 2 and the results are presented in Section 3. Section 4 provides a discussion. In Section 5 a detailed comparison is made with the recent results by Smith (1987) and the conclusions are given in Section 6.

2 Observations

JHK (and when possible *L*) photometry was carried out with the InSb photometer attached to the 1.5-m telescope at Cerro Tololo Interamerican Observatory on the nights of 1986 March 16–21. Most measurements were taken through a 9-arcsec diaphragm and 30-arcsec beam separation in the E–W direction except where the fields were too crowded; in these cases, a suitable combination of aperture, chopping throw and direction was used after inspection of the fields on the TV screen. The symmetry of the alternate beams was always monitored on the chart recorder in order to detect possible contamination effects. All measurements were compared against a set of CTIO standard stars (Elias *et al.* 1982) and reduced using CTIO's reduction facilities at La Serena. Our sample of stars was chosen in an unbiased manner always attempting to observe as many stars as possible within the boundaries of the open clusters Tr 14, Tr 15, Tr 16 (which included Cr 232) and Cr 228. In most cases, the stars had accurate visual photometry available.

3 Results

The results from the *JHKL* photometry are presented in Table 1 together with the corresponding observational errors. For completeness, those stars observed by Thé, Bakker & Tjin A Djie (1980a) and Thé & Groot (1983) and absent in our observing programme are also included (no observational errors are quoted for these) in Table 1. The corresponding *J–H* and *H–K* diagram is shown in Fig. 1 where nine background highly reddened stars in the direction of Tr 14, Tr 15, Tr 16 and Cr 228 found and measured by Tapia (1981) are also included. The infrared data were combined (when available) with *UBVRI* photometry by Feinstein (1969), Feinstein *et al.* (1973), Feinstein *et al.* (1976), Herbst (1976), Forte (1978), Feinstein *et al.* (1980), Thé *et al.* (1980a), Turner & Moffat (1980), Thé *et al.* (1980b), Feinstein (1982) and Thé & Groot (1983). The two-dimensional spectral types used here have been reported by Walborn (1973, 1982a), Herbst (1976), Levato & Malaroda (1981, 1982) and Levato *et al.* (1987, private communication). When spectral-type determinations were not available, Johnson & Morgan's (1953) Q-method and its equivalent method by Feinstein *et al.* (1973) were used to obtain photometric spectral types (assuming luminosity class V). For the stars with spectroscopic determinations, the photometrically determined spectral types differed only by one subtype or less, with only one exception. Also listed in Table 1 are *V* magnitudes and spectral types (those computed from *UBV* photometry are given in parentheses). The resulting *V–K* versus *B–V* diagram is shown in Fig. 2. In both these diagrams and in the following analysis, the stars in the cluster known as Cr 232 are identified as members of Tr 16 as demonstrated by Feinstein *et al.* (1973) and corroborated by the present results.

Colour excesses were computed for all stars in our sample for which *UBV* (and *R*) data were available. Intrinsic colours were adopted from FitzGerald (1970), Johnson (1968) and Koornneef (1983) for the determined or computed spectral type of each star. In those cases in which the *RI* photometry was observed and reported in the Kron–Cousin system, the colours were converted

Table 1. Near-infrared photometry.

Name	K	J-K	H-K	K-L	V	Sp.Ty.	Notes
Tr14 6	10.15 .01	.18 .02	.05 .01		11.23	B1V	
Tr14 11	10.78 .03	.46 .03	.15 .04		12.78	(B8)	Var.
Tr14 12	11.15 .02	.47 .03	.12 .01		12.64	(B2)	
Tr14 13	11.37 .02	.34 .03	.16 .02		12.63	(B3)	
Tr14 14	9.79 .01	.76 .01	.29 .01	.50 .21	12.62	(Late)	N.M.
Tr14 15	8.66 .04	1.56 .04	.82 .03	1.16 .06	12.01	(B7)	
Tr14 16	12.69 .04	.01 .05	-.03 .04		13.60	(B5)	
Tr14 17	11.52 .04	.25 .06	.06 .04		12.65	(B3)	
Tr14 18	10.51 .01	.33 .01	.12 .01		12.15	(B1)	
Tr14 20	8.46 .01	.18 .01	.05 .01	.09 .07	9.61	O6V	
Tr14 21	9.32 .01	.25 .01	.06 .01	.15 .14	10.88	O9V	
Tr14 22	10.80 .01	.36 .01	.14 .01		12.34	(B2)	
Tr14 24	10.46 .01	.35 .03	.09 .01		12.12	(B2)	
Tr14 25	11.90 .04	.28 .05	.23 .05		12.88	(B5)	Var.
Tr14 26	10.27 .01	.42 .01	.17 .01		11.93	B1	Var.
Tr14 27	9.76 .01	.35 .01	.13 .01	.16 .21	11.32	(B1)	
Tr14 28	10.65 .01	.34 .01	.09 .01		12.50	(B1)	
Tr14 30	8.25 .01	.33 .01	.11 .01	.17 .03	10.08	B0III:IV	
Tr14 43	10.51 .03	.33 .02	.12 .01				
Tr14 44	11.15 .01	.22 .02	.02 .01				
HD 93129	5.04	.17	.02	-.04	6.97	O3V((f))	
Tr14 160	10.85 .02	.27 .03	.11 .02				
Tr14 161	11.04 .03	.28 .03	-.02 .03				
Tr14 162	12.18 .03	.08 .03	.00 .03				
Tr15 1	8.01 .03	.06 .03	.06 .05	-.03 .07	8.36	O9II	
Tr15 2	9.06 .03	.01 .03	.00 .05	-.10 .19	9.47	O9III	
Tr15 3	10.02 .03	.07 .03	.09 .05	.20 .23	10.57	B2Vn	
Tr15 4	10.62 .04	-.03 .04	-.03 .05	.12 .09	11.00	B1Vn	
Tr15 5	10.83 .03	-.01 .03	-.01 .04		11.49	B5V	
Tr15 6	11.68 .04	.02 .04	-.06 .05		12.49	(B5)	Var.
Tr15 7	9.68 .03	.11 .05	.01 .04	.20 .12	10.58	B2.5Vn	
Tr15 8	11.37 .04	.23 .04	.04 .05		12.92	(B8)	
Tr15 9	11.33 .04	.24 .04	.07 .05		12.59	B1V	
Tr15 10	10.95 .02	.02 .02	.01 .02		11.55	B2V	
Tr15 12	12.33 .03	.21 .03	.09 .03		13.37	(B3)	
Tr15 13	10.27 .01	.01 .01	-.03 .01		10.78	B1V	
Tr15 14	9.76 .03	.13 .02	.04 .04	.18 .13	10.57	B2.5IV-V	
Tr15 15	9.51 .03	.07 .02	.00 .04	-.15 .11	10.08	B0.5IV-V	
Tr15 16	1.82 .03	1.28 .02	1.34 .04	.45 .05	8.82	M2Ia	Var. RTCar
Tr15 18	7.15 .03	.82 .02	.30 .02	.30 .05	11.28	O9.5I-II	
Tr15 21	12.12 .04	.20 .04	.05 .05		13.13	(B7)	
Tr15 22	12.08 .04	.21 .04	.05 .05		13.17	(B7)	
Tr15 23	10.40 .01	.09 .01	.02 .01	.64 .19	11.12	B0V	
Tr15 24	11.34 .03	.13 .03	-.04 .03		12.14	(B3)	
Tr15 25	11.86 .04	.15 .04	.04 .05		12.73	B5V	
Tr15 26	10.30 .03	.08 .03	-.03 .04		10.70	B1V	
Tr15 27	11.26 .03	.63 .04	.28 .05		12.83	B3	
Tr15 28	8.24 .03	.92 .03	.15 .05	.12 .09	12.16	B7Ib	
Tr15 29	12.15 .04	.19 .04	.03 .06		12.92	(B7)	
Tr15 30	12.50 .03	-.01 .04	-.09 .06		12.92	(B5)	
Tr15 31	12.45 .03	.04 .04	.01 .03		13.02	(B5)	
Tr15 32	12.13 .04	.08 .05	.03 .06		12.71	(B5)	
Tr15 33	11.77 .02	.04 .02	.02 .02		12.27	(A0V-B5)	
Tr15 34	12.12 .03	.20 .03	.02 .03		13.18	(B7)	

Table 1 – *continued*

Name	K	J-K	H-K	K-L	V	Sp.Ty.	Notes
Tr15 35	11.93 .01	.22 .01	-.02 .01		13.25	(B8)	
Tr15 36	12.62 .03	.24 .03	.05 .03		13.76	(B7)	
Tr15 37	12.94 .03	.16 .04	.09 .04		13.88	(B8)	
Tr15 38	12.72 .03	.34 .05	.11 .03		13.68	(B7)	
Tr15 39	9.09 .01	.91 .01	.18 .01	.17 .11	12.72	(Late)	N.M.
Tr16 1	9.59 .02	-.01 .03	-.06 .01		9.53	O9.5Vn	
Tr16 2	10.27 .02	.07 .03	.02 .01		10.80	B1.5V:+A?	
Tr16 3	9.45 .03	.19 .04	.03 .03	.07 .11	10.17	O9:V:	
Tr16 4	10.43 .04	.05 .05	.01 .03	-.16 .26	11.00	B2	Bin.
Tr16 8	10.31 .02	-.03 .03	-.05 .01		10.90	B1.5Vn	
Tr16 9	8.77 .01	.02 .01	.02 .01	.05 .11	9.79	O9.5V	
Tr16 10	8.53 .02	.25 .03	.10 .01	.12 .06	9.83	B0Vn	
Tr16 11	10.55 .01	.08 .01	.02 .01		11.25	(B1)	
Tr16 12	10.25 .03	.26 .03	.09 .02	.21 .17	11.44	(B1)	
Tr16 13	10.12 .01	.13 .01	.06 .01		10.76	(B1)	
Tr16 14	10.18 .01	.09 .02	.13 .01		11.50	(O-B0)	
Tr16 15	9.84 .01	.24 .02	.07 .01	.26 .15	11.28	(B1)	
Tr16 16	9.78 .01	.07 .02	.01 .01	.14 .24	10.87	B2Vb	
Tr16 17	10.08 .01	.10 .01	.03 .01		11.01	(O-B0)	
Tr16 20	9.96 .01	-.04 .02	-.03 .01	.29 .20	10.20	B1:V	
Tr16 21	8.99 .01	.30 .01	.09 .01	.12 .17	10.93	(O-B0)	
Tr16 22	8.81 .03	.46 .03	.17 .01	-.06 .17	11.01	(B1)	
Tr16 23	8.29 .03	.35 .03	.12 .01	-.05 .08	9.97	O7V	
Tr16 25	10.21 .01	.38 .01	.13 .01	.54 .25	11.66	(B3)	
Tr16 26	10.61 .01	.28 .02	.12 .01		11.89	(B1)	
Tr16 27	10.55 .03	.00 .04	.02 .03	.45 .44	11.06	(B1)	
Tr16 28	10.69 .03	.11 .03	.02 .01		11.70	B1	Var.
Tr16 29	9.95 .02	.25 .03	.10 .01	.53 .11	11.36	B1	
Tr16 30	8.54 .02	.59 .03	.10 .01	.01 .09	11.17	B1	Bin.
Tr16 33	11.37 .03	.21 .03	.08 .01		11.83	(B2)	
Tr16 34	8.05 .03	.24 .03	.08 .01	.07 .06	9.31	O8-9:V:+Comp.	
Tr16 36	5.51 .01	.91 .01	.15 .01	.21 .07	9.44	(Late)	N.M.
Tr16 37	12.36 .03	.10 .04	.11 .04		12.95	(B5)	
Tr16 38	12.02 .04	.26 .05	.07 .03		13.37	(B5)	
Tr16 39	10.88 .03	.36 .03	.11 .02		12.82	(B3)	
Tr16 43	10.71 .01	.32 .02	.05 .01		12.23	(B7)	
Tr16 44	11.05 .01	.44 .02	.20 .01		13.67	(B3)	
Tr16 46	10.37 .01	.20 .01	.06 .01		11.71	(B3)	
Tr16 47	11.64 .03	.08 .03	.01 .03		12.91	(B3)	
Tr16 49	11.57 .03	.19 .03	.04 .03		13.48	(B5)	
Tr16 50	11.32 .01	.33 .01	.11 .01		12.92	(B5)	
Tr16 52	11.28 .04	.24 .04	-.06 .03		12.58	(B3)	
Tr16 53	9.94 .02	.75 .03	.16 .01	.36 .19	13.26	(Late)	N.M.
Tr16 54	11.62 .03	.28 .05	.13 .03		12.85	(B3)	
Tr16 55	1.23 .03	.17 .03	.04 .02		12.22	(O-B0)	
Tr16 56	12.44 .02	.30 .03	.13 .03		13.43	(B8)	N.M.
Tr16 57	11.64 .01	.19 .01	.07 .01		12.90	(B7)	
Tr16 58	11.69 .03	.01 .03	-.06 .02		12.42	(Late)	N.M.
Tr16 59	11.16 .01	.38 .02	.23 .02		12.36	(B2)	
Tr16 67	10.56 .03	1.19 .04	.64 .02	2.22 .06	13.70	(B8)	N.M.
Tr16 68	9.55 .03	1.82 .04	1.15 .05	2.23 .06	12.48	(B3)	Cont.
Tr16 72	11.38 .04	.11 .04	.05 .04		12.10	(B2)	
Tr16 73	10.40 .01	.21 .01	.03 .02		11.90	(B1)	
Tr16 76	9.56 .01	.25 .01	.07 .01		11.19	(O-B0)	
Tr16 77	11.84 .04	-.64 .04	-.67 .03		12.08	(B3)	Cont.

Table 1 – *continued*

Name	K	J-K	H-K	K-L	V	Sp.Ty.	Notes
Tr16 78	9.22 .02	.66 .03	.13 .01	.13 .10	12.19	(Late)	N.M.
Tr16 79	11.32 .03	.47 .04	.13 .02		13.68	(Late)	
Tr16 94	9.52 .01	.05 .01	.01 .01	-.01 .18	9.86	B1Vn	
Tr16 100	7.62 .01	.14 .01	.04 .01	.16 .09	8.61	O6V((f))	
Tr16 104	8.33 .03	-.01 .03	-.03 .02	-.03 .11	8.77	O7V((f))+Comp.?	
Tr16 110	7.74 .03	.30 .03	.10 .01	-.01 .07	9.31	O7V	
Tr16 112	7.84 .02	.30 .03	.10 .01	.05 .07	9.29	O4.5V((f))	
Tr16 115	9.38 .03	.01 .03	-.02 .01	-.41 .21	10.15	O9V	
HD303308	7.62 .03	.05 .03	.02 .01	-.14 .02	8.17	O3V((f))	
HD 93343	8.42 .03	.23 .03	.08 .01	.02 .08	9.47	O8Vn	
HD 93162	5.74 .01	.52 .02	.22 .01	.31 .07	8.09	WN6-A	
HD 93205	7.43 .01	.05 .02	.00 .01	.01 .08	7.75	O3V	
HD 93204	7.93 .01	.05 .01	.01 .01	.12 .08	8.42	O5V	
Tr16 132	10.55 .01	.52 .02	.21 .01				
Tr16 133	10.30 .01	.28 .01	.11 .03				
Tr16 134	10.22 .01	.22 .02	.08 .01				
Tr16 135	11.34 .04	.00	.06 .04				
Tr16 136	10.67 .03	.22 .03	.08 .01	.83 .32			
Tr16 139	11.38 .03	.08 .04	.02 .02				
Tr16 140	11.74 .07	-.07 .07	-.03 .06				
Tr16 141	11.70 .01	-.11 .02	-.06 .01				
Tr16 142	11.02 .01	.27 .02	.02 .01				
Tr16 143	10.35 .01	.27 .02	.03 .01				
Tr16 145	11.42 .02	.15 .03	.07 .02				
Tr16 146	11.85 .03	.22 .03	.13 .02				
Tr16 149	7.13 .01	.74 .03	.26 .01	.31 .07	10.73	O4f	
Tr16 150	11.45 .01	.13 .02	.05 .01				
Tr16 152	7.71 .01	.53 .01	.07 .01	.05 .08			
Tr16 154	12.31 .03	-.01 .04	-.03 .03				
Tr16 155	12.20 .02	.02 .03	.03 .03				
Tr16 174	10.65 .01	.11 .01	-.05 .01				
Cr232 31	9.56 .01	.12 .01	.03 .01	-.09 .19	10.44	B0Vn	
Cr232 32	10.69 .01	.10 .01	.03 .01		11.05	(Late)	N.M.
Cr232 35	7.33 .01	.60 .01	.10 .01	.14 .15	9.85	(Late)	N.M.
Cr232 80	10.85 .01	.13 .01	.00 .01		12.14	(B3)	
HD 93268	8.94 .01	.07 .01	.02 .01	.11 .13	9.32	A0VSn	
HD 93250	6.66 .01	.11 .01	.03 .01		7.37	O3V((f))	
HD 93161	6.95 .01	.16 .01	.04 .01	.03 .09	7.82	O6.5V((f))	
HD 93160	7.07 .01	.15 .01	.04 .01	.10 .09	7.82	O6III(f)	
Cr232122	10.57 .01	.11 .01	.01 .01		11.32	(B2)	
Cr232123	11.47 .04	.39 .04	.19 .04				
Cr232124	9.91 .01	.27 .01	.08 .01	.15 .25	11.13	(B1)	
Cr232125	10.51 .01	.33 .01	.03 .01		12.15	(B5)	N.M.
Cr232126	9.20 .01	.35 .01	.12 .01	.28 .12	10.97	(B1)	
Cr232127	9.24 .08	-.19 .08	-.11 .08		10.70	O7-9 SB?-pec?	
Cr232129	10.15 .01	.35 .01	.13 .01		11.57	(B3)	
Cr232130	11.45 .04	.41 .04	.20 .04		12.72	(B3)	
Cr232131	12.21 .01	.43 .03	.17 .02		13.48	(B3)	
Cr232160	10.80 .01	.18 .01	.04 .01				
Cr232161	10.85 .01	.37 .01	.05 .01				
Cr232163	11.39 .03	.18 .03	.03 .02				

Table 1 – *continued*

Name	K		J-K		H-K		K-L		V	Sp.Ty.	Notes
Cr232164	11.76	.03	-.04	.02	-.06	.02					
Cr232165	10.96	.01	.37	.01	.06	.01					
Cr232166	12.06	.03	.06	.04	.00	.04					
Cr232167	11.56	.03	.33	.02	.09	.02					
Cr232169	12.04	.03	.18	.03	.06	.03					
Cr232170	11.85	.03	.14	.03	.01	.02					
Cr232171	11.95	.03	.29	.03	.09	.03					
Cr232173	8.45	.01	.71	.01	.15	.03					
Cr232174	10.59	.01	.18	.01	.02	.01					
Cr228 1	7.07		.17		.06		-.02		8.04	O6III(f)	HD93130
Cr228 2	8.50		.05		.05		.35		8.48	B9.5Vb	HD93191
Cr228 3	5.85	.02	.22	.01	.13	.01	.30	.03	6.48	WN7	HD93131
Cr228 4	7.68	.02	.25	.01	.08	.01	.10	.04	8.68	B0.5Iab	HD305520
Cr228 5	8.70	.02	.02	.01	.00	.01	-.01	.08	8.94	O7III((f))	HD305536
Cr228 6	7.39		.16		.01		-.06		8.08	O7III((f))	HD93222
Cr228 8	9.24	.02	.10	.01	.03	.01	.01	.14	9.69	B0.5V+Comp.	HD305522
Cr228 9	9.35	.02	.05	.01	.02	.01	-.25	.23	9.56	(B9)	N.M.
Cr228 10	4.57	.02	1.01	.01	.30	.01			9.40	(Late)	N.M.
Cr228 12	6.80		.58		.24		.15		9.47	B2.5Ia:	
Cr228 13	8.95	.02	-.01	.01	-.02	.01			8.97	B1VN	HD93056
Cr228 14	8.74	.02	-.05	.01	-.03	.01	.06	.08	8.72	O9.5V	HD93027
Cr228 15	6.95	.02	.40	.01	.07	.01	.08	.04	8.59	G5	N.M.
Cr228 19	10.29	.02	.03	.01	-.01	.01	.44	.20	10.52	B1:V:SB2	
Cr228 20	8.39	.03	.60	.01	.08	.01	.05	.05	10.41	B2	Cont.
Cr228 21	9.16	.02	.02	.01	-.01	.01	.03	.13	9.31	O7.5Vn	
Cr228 22	8.66		.34		.10		.27		9.71	O9.5IV	HD305518
Cr228 26	10.03	.02	.12	.01	.04	.01			10.63	A0Vn	
Cr228 27	8.55		-.07		-.09		.03		10.28	B3	HD93028
Cr228 28	9.58	.02	.01	.01	-.01	.01	-.36	.36	9.74	B1V+B1V	Var.
Cr228 29	10.04	.02	.04	.01	.01	.01			10.21	B9.5Vp?	
Cr228 32	7.58		.15		.03		-.06		8.49	O9II	HD305523
Cr228 33	5.36	.02	.23	.01	.07	.01	.10	.03	6.28	O9Ib(N)Var	HD93206
Cr228 34	5.93	.02	.94	.01	.16	.01	.15	.03	9.82	(Late)	N.M.
Cr228 35	10.17	.02	-.03	.01	.01	.01			10.18	B9.5Vb	
Cr228 36	9.78	.03	.07	.01	.00	.01	.10	.22	10.23	B0.5:V:+B0.5:V:	
Cr228 38	8.59		.30		.04		.25		10.20	O5V	HD305532
Cr228 45	7.82	.02	.57	.01	.09	.01	.06	.05	10.18	(Late)	N.M.
Cr228 48	11.08	.03	-.05	.02	-.02	.02			11.00	B1.5Vb	
Cr228 50	10.36	.02	.45	.01	.20	.01			12.04	(B3)	
Cr228 57	9.68		.08		-.08				9.86	A2V	HD305519
Cr228 65	7.83		.10		.01		-.05		8.44	O6.5V((f))	HD93146
Cr228 67	8.63	.02	.04	.01	.00	.01			8.77	O9V	
Cr228 68	10.17	.02	.06	.01	.02	.01	-.73	.55	10.16	B1Vn	Cont.
Cr228 69	9.71	.02	-.01	.01	-.02	.01			9.76	B0Vn	
Cr228 70	8.48	.02	.50	.01	.10	.01	.22	.06	10.76	(B7)	N.M.
Cr228 71	8.94	.02	.59	.01	.09	.01	.20	.06	11.40	(B8)	N.M.
Cr229 73	10.16	.02	.62	.01	.09	.01			12.92	(Late)	N.M.
Cr228 76	10.94	.03	.14	.01	.03	.01			12.44	(B5)	
Cr228 77	10.51	.03	.22	.01	.08	.01			11.57	(B2)	
Cr228 79	8.37	.02	.67	.06	.11	.02			11.13	(Late)	N.M.
Cr228 80	8.55		-.07		-.09		.03		10.28	B3	HD93028
Cr228 97	8.38		.43		.16		.01		10.36	O5V	
Cr228 98	7.75		.37		.15		.10		10.00	O6V	HD305525
Cr228102	9.27	.02	.92	.01	.34	.01	.31	.08			

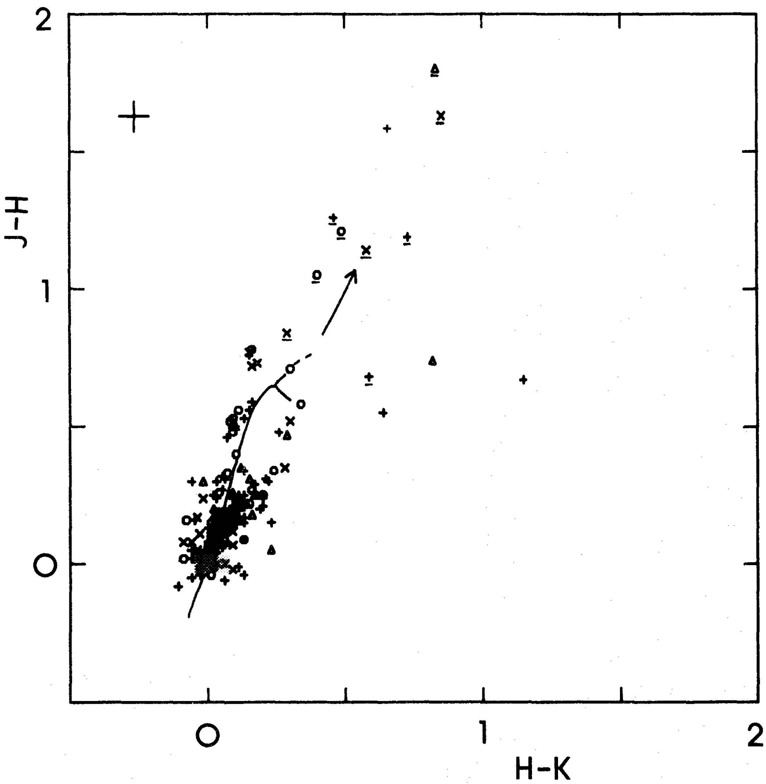

Figure 1. *J–H* versus *H–K* diagram of all observed stars in the open clusters Tr14 (△), Tr15 (×), Tr16/Cr232 (+) and Cr228 (○). Also included are 13 stars observed by Thé *et al.* (1980a) and Thé & Groot (1983). The underlined symbols are for background stars in the field of the respective clusters observed by Tapia (1981). The arrow represents the standard reddening vector for $A_V = 2$, the continuous and broken lines represent the unreddened main sequence and supergiant locus respectively.

to Johnson's *VRI* system using the relations by Bessell (1979). This procedure may lead to larger uncertainties in the *VRI* colour indexes for some stars.

In order to get an indication of the ultraviolet extinction properties in the Carina region, 18 LWR spectra of 12 O-type stars in the area were obtained from the *IUE* log files. Although the errors were large, a weak tendency toward weaker 2200 Å humps was found in this sample as compared to the average values (Savage *et al.* 1985). A similar trend was also reported by Aiello *et al.* (1987, 1988) who have recently compiled an atlas of ultraviolet extinction in this and many other regions; the details of the UV extinction curve can be found in these papers.

4 Discussion

In order to prevent (to a high degree) our sample from being contaminated from field stars, we restricted ourselves to stars with spectral types earlier than B9 and excluded also all those for which there was photometric or spectroscopic evidence of being non-member stars; also, known variable or binary stars were rejected.

4.1 REDDENING

Fig. 3 shows the *E*(*J–H*) versus *E*(*H–K*) colour excess diagram for this sample. The mean characteristics of the diagram are:

(i) There is a spread of roughly 3 mag in the extinction value in the direction of the 'normal'

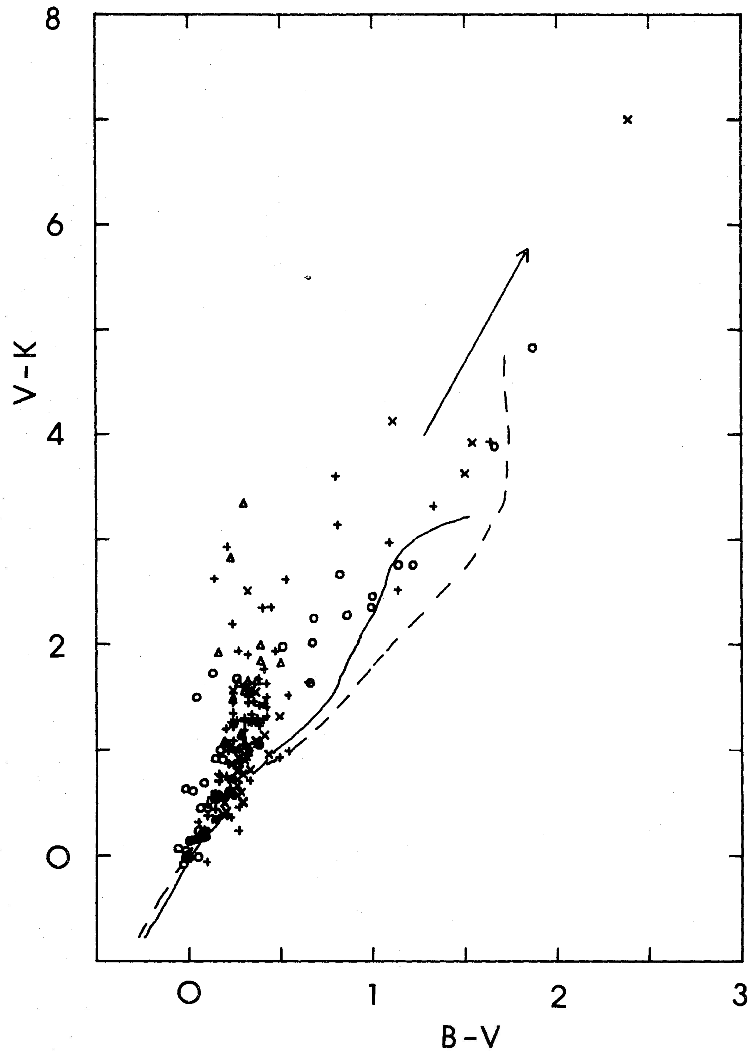

Figure 2. *V–K* versus *B–V* diagram for all observed stars in Tr 14, Tr 15, Tr 16/Cr 232 and Cr 228 with *BV* photometry available in the literature. All symbols are as in Fig. 1.

reddening vector (e.g. Tapia 1981), though the average extinction for each of the four clusters is different (see later).

(ii) There are five stars which fall outside the expected observational scatter, two O-type stars (Tr 15 − 18 and Tr 16 − 149) which are reddened by an extra 1 or 2 mag from the rest, one B7 star (Tr 14 − 15) which shows a large *K–L* excess, and two stars (Tr 15 − 28 and Tr 16 − 52) for which only large observational errors can be invoked to explain their position in the diagram; these last two were excluded from our analysis.

It is important to note from Figs 1 and 3 that the reddening vector described by the ratio $E(J-H)/E(H-K) = 1.5$–1.6, characteristic of very dense molecular star forming clouds such as Ophiuchus and Taurus (Elias 1978a, b) and the Galactic Centre (Becklin *et al.* 1978), cannot be compatible with the near-infrared photometry of the stars in the Carina clusters or even of the highly reddened background stars in these directions; on the other hand, the reddening in Carina can be better described by the value [transformed to the CIT/CTIO photometric system following the relations by Elias *et al.* (1983) and McGregor & Hyland (1981)] $[E(J-H)/E(H-K)]_{\mathrm{CIT}} = 1.91$ obtained independently by Jones & Hyland (1980) and Tapia (1981) for highly reddened field stars in several directions.

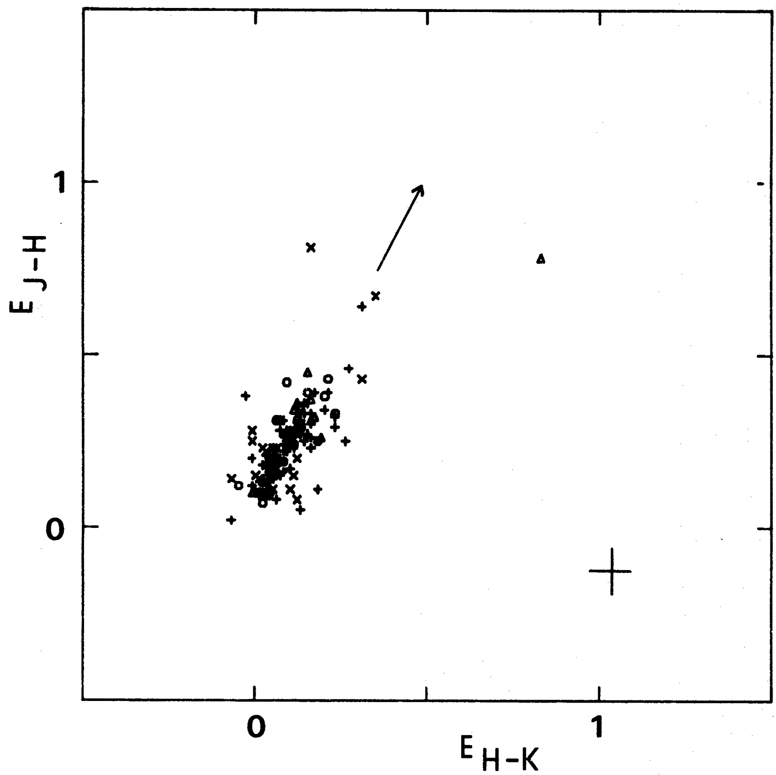

Figure 3. Two-colour excess diagram for all observed stars believed to be members of Tr 14, Tr 15, Tr 16/Cr 232 and Cr 228 (see text). The cross at the lower right shows the typical uncertainties for each point. All other symbols are as in Fig. 1.

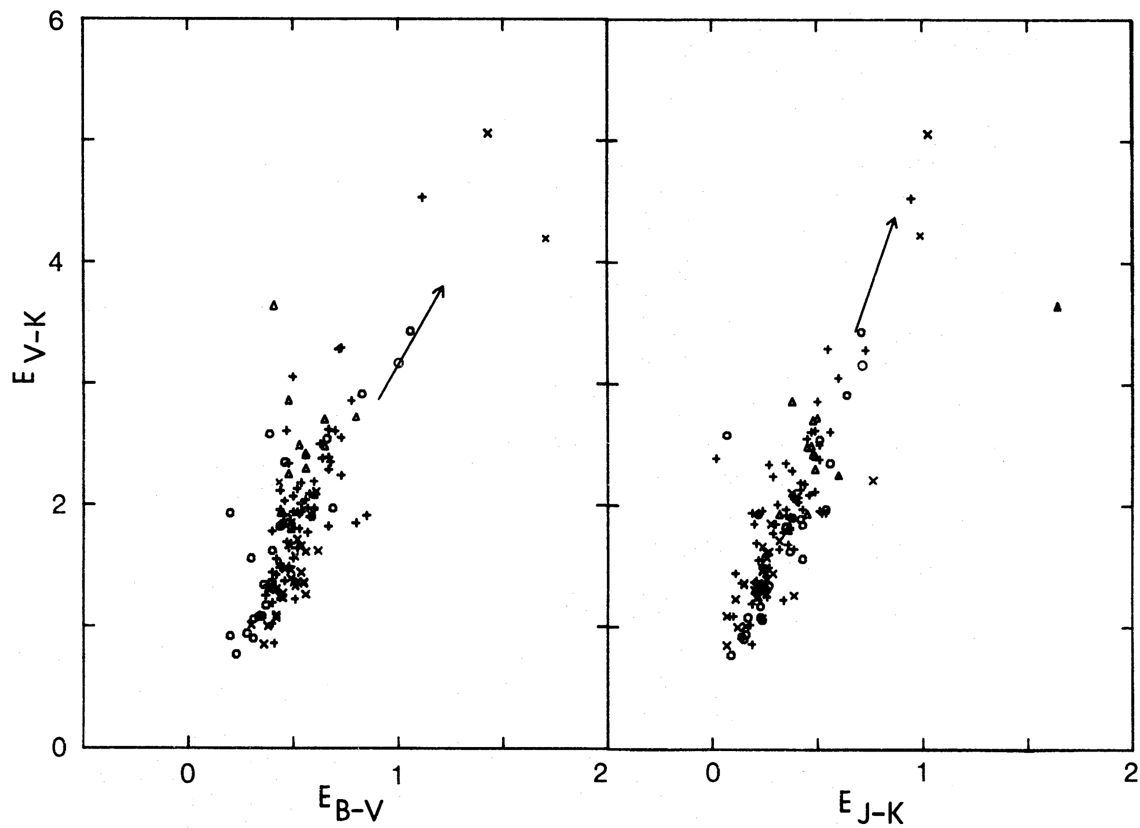

Figure 4. Two-colour excess diagrams for stars believed to be members of the clusters Tr 14, Tr 15, Tr 16/Cr 232 and Cr 228 (see text). The arrow represents the standard reddening vector for $A_V = 1$. All other symbols are as in Fig. 1.

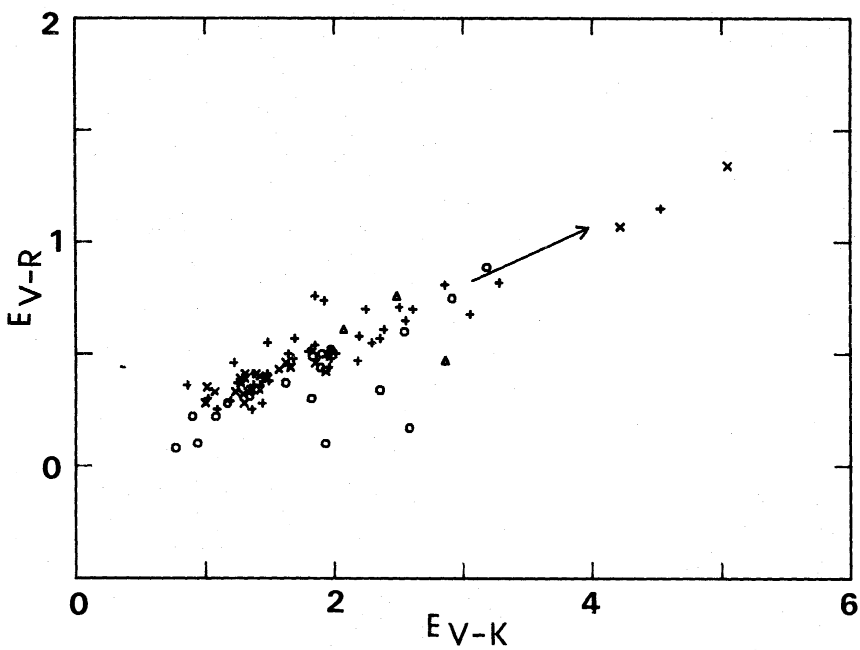

Figure 5. Two-colour excess diagram, for stars believed to be members of the studied clusters which had *BVR* photometry available in the literature. Symbols are as in Fig. 4.

A comparison between the near-infrared and the visual data provided some unexpected results. Fig. 4(a) shows an $E(V-K)$ versus $E(B-V)$ plot for the stars in our working sample. It can clearly be seen that no single reddening vector can fit all observations. Except for only very few cases, the extremely large scatter cannot be explained by observational errors. Therefore, unless more than 50 per cent of the sample shows chromospheric activity, the scatter and tendency

Table 2. Colour excesses and derived extinctions.

	Tr15	Tr14	Tr16 + Cr232	Cr228
E(V-K)	1.37 (.24)	2.34 (.33)	1.93 (.49)	1.76 (.74)
Av (E(V-K))	1.51 ± .05	2.57 ± .10	2.13 ± .07	1.94 ± .16
E(B-V)	0.48 (.07)	0.56 (.10)	0.54 (.12)	0.46 (.23)
Av (E(B-V))	1.49 ± .04	1.74 ± .09	1.74 ± .01	1.43 ± .14
E(J-K)	0.22 (.07)	0.45 (.08)	0.34 (.15)	0.34 (.18)
Av (E(J-K))	1.42 ± .08	2.91 ± .14	2.21 ± .12	2.20 ± .23
E(V-R)	0.37 (.05)	0.61 (.15)	0.51 (.16)	0.46 (.25)
Av (E(V-R))	1.40 ± .04	2.31 ± .33	1.92 ± .08	1.74 ± .24
No. (BVK)	29	13	62	25
No. (RI)	24	3	40	15

Notes:
Standard deviations for a single measurement are given in parenthesis.
Last two lines show the number of stars with *BVK* and *RI* photometry used for statistics.

towards larger values of $E(V-K)/E(B-V)$ is due to variable and anomalous interstellar extinction. This result is not new and has been reported in terms of *UBVRI* photometry (see Herbst 1976; Forte 1978; Feinstein 1982) and *JHKL* photometry of a few stars (Thé *et al.* 1980a; Thé & Groot 1983). Nevertheless, when the $E(J-K)$ (Fig. 4b) or $E(V-R)$ (Fig. 5) colour excess indexes are compared to $E(V-K)$, the scatter is substantially reduced and, within the uncertainties, almost all stars appear to be reddened following a single law. In fact, 'normal' reddening vectors fit well to the great majority of the stars in these diagrams. Table 2 shows the average values of several colour indices computed for each individual cluster. Also shown in Table 2 are the corresponding values of the total *V*-band extinction A_V assuming the average extinction law given by Savage & Mathis (1979). For the least reddened cluster, Tr15, all values of A_V are in agreement, but for Tr14, Tr16 and Cr228 the values implied by the measured $E(B-V)$ are in complete disagreement with those computed from $E(V-R)$ and $E(J-K)$ or even (though not shown in Table 2) any other colour index from *VRIJHKL* photometry. This is more clearly illustrated by the analysis of the values of the several colour excess ratios given in Table 3 (the standard deviation for each measurement is presented in parentheses). In all cases, except when $E(B-V)$ is used, the values coincide, within the observational errors, with the average standard value. Furthermore, the ratio $E(V-K)/E(B-V)$ was found to increase with optical depth, as expressed by the value of $E(V-K)$ while, for example, the value of $E(V-K)/E(J-K)$ did not show any correlation with $E(V-K)$ (Fig. 6).

In order to verify if such behaviour could be attributed to peculiarities in the atmospheric/chromospheric emission of some of the stars, the sample was divided into several spectral categories, namely:

(i) early-type supergiants,
(ii) stars with Of spectra,
(iii) O and B0 stars without emission lines,
(iv) normal B1–B3 stars,
(v) normal B5–B9 stars.

In all categories and regardless of the method used for the spectral type determinations, the fraction of stars showing anomalous $E(V-K)/E(B-V)$ ratios was similar, strongly indicating.

Table 3. Colour excess ratios.

	Tr15	Tr14	Tr16 + Cr232	Cr228	All	Standard Value*
E_{J-K}/E_{V-K}	0.15 (.05)	0.19 (.03)	0.16 (.05)	0.15 (.15)	0.17 (.07)	0.19
E_{B-V}/E_{V-K}	0.34 (.05)	0.24 (.04)	0.28 (.06)	0.25 (.09)	0.28 (.07)	0.37
E_{V-R}/E_{V-K}	0.27 (.03)	0.26 (.08)	0.27 (.05)	0.23 (.05)	0.26 (.05)	0.29
E_{V-I}/E_{V-K}	0.57 (.08)	0.49 (.05)	0.56 (.11)	0.54 (.16)	0.56 (.11)	0.59
E_{V-J}/E_{V-K}	0.85 (.05)	0.80 (.03)	0.82 (.05)	0.81 (.05)	0.82 (.04)	0.82
E_{V-H}/E_{V-K}	0.97 (.04)	0.94 (.02)	0.95 (.03)	0.95 (.03)	0.95 (.03)	0.93
$\Delta(B-V)/(E_{V-K} - 1.28)$	0	-0.27 (.08)	-0.26 (.10)	-0.27 (.15)	-0.27 (.07)	0

* Savage and Mathis (1979).

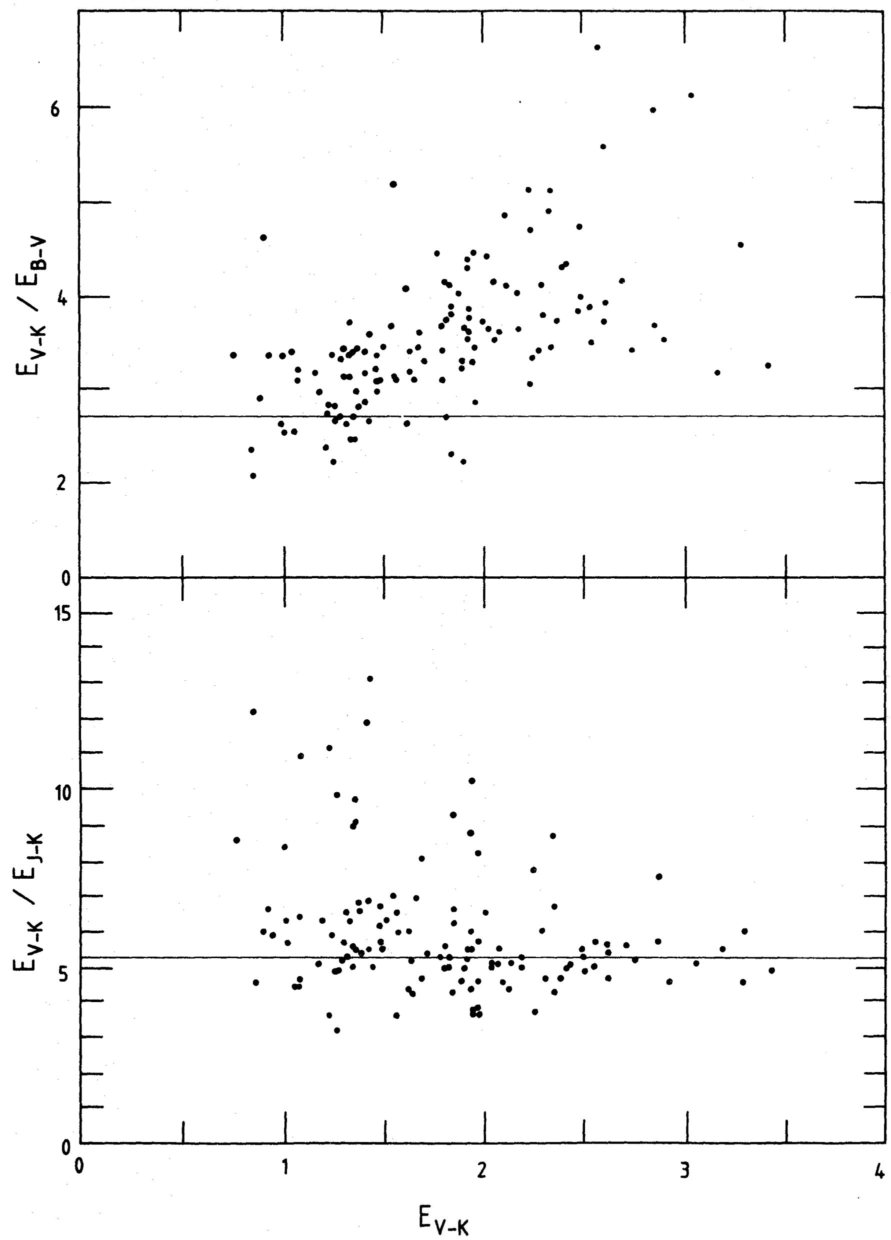

Figure 6. Colour excess ratios $E(V-K)/E(B-V)$ (top panel) and $E(V-K)/E(J-K)$ (bottom panel) as a function of $E(V-K)$ for all stars believed to be members of the studied clusters. The horizontal lines are drawn at the 'normal' values of the colour excess ratios.

that, except for a few isolated cases, the effect is due to the interstellar extinction properties in the direction of these clusters.

The observational evidence presented in this paper can be summarized by the following points:

(i) The colour excess ratios for the stars in all clusters are constant and resemble the 'standard' extinction law (e.g. Savage & Mathis 1979) except those involving $E(B-V)$.

(ii) No correlation whatsoever was found between the anomalous colour index $E(B-V)$ and the spectral type or the presence (or absence) of spectral emission lines.

(iii) The total average amount of extinction, as measured by $E(V-K)$ varies from cluster to cluster and with large scatter within each, Tr 14 being the highest reddened cluster and Tr 15 showing the lowest extinction, the latter being also the only cluster to have a 'normal' colour excess ratio $E(V-K)/E(B-V)$.

All these characteristics point towards the following main conclusion: The extinction properties in the direction of the clusters Tr 14, Tr 16/Cr 232 and Cr 228 are certainly anomalous in the sense that the $E(B-V)$ colour excess index is systematically lower than under a 'normal' extinction law while all other colour excess indices seem to behave in a way similar to the general interstellar medium. The latter characteristic makes the extinction in the Carina nebula quite different from that in dense molecular clouds, like those in Ophiuchus, Taurus and Orion where most colour excess ratios differ from the standard values. It seems clear that the interstellar and intracluster dust grains in the Carina clusters show quite different extinction properties.

Let us define the quantity $\Delta(B-V)$ as the 'deficiency' in the measured $E(B-V)$ colour excess index as compared to that expected from the measured $E(V-K)$ and a normal extinction law, i.e.

$$\Delta(B-V)=E(B-V)-\frac{1.1}{3.1}E(V-K).$$

Fig. 7 shows this quantity plotted against $E(V-K)$. $\Delta(B-V)$ is zero for all values of $E(V-K)$ <1.28 (including most stars in Tr 15) while for larger values $\Delta(B-V)$ decreases linearly with $E(V-K)$ and at the same time, the scatter seems to get greater. We interpret this behaviour in the following way: The infrared extinction is 'normal' up to a value of $E(V-K)\simeq 1.28$, corresponding to a $A_V \approx 1.41$ which is caused by foreground material. Starting at that optical depth where the 'nearest' cluster is located, the denser interstellar intracluster material begins. This is composed of anomalous dust grains which are processed in such a way that their extinction properties are characterized by producing excesses in the $B-V$ colour index which are lower for a given optical depth than that caused by the general interstellar medium while the other colour indices behave 'normally'.

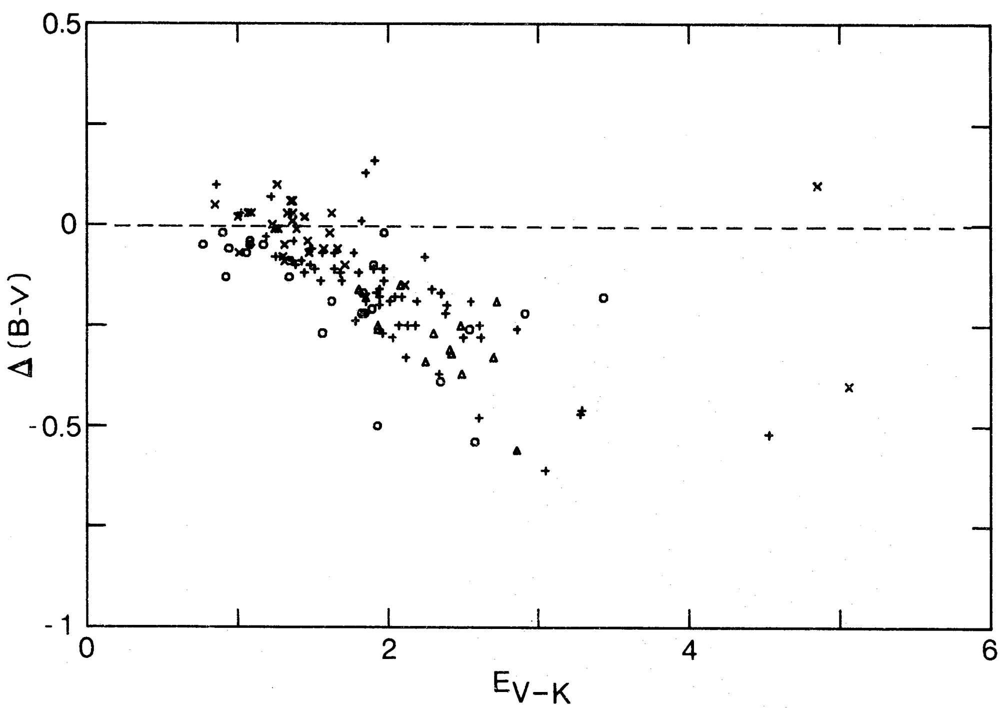

Figure 7. $\Delta(B-V)=E(B-V)-0.355\,E(V-K)$ versus $E(V-K)$ plot for all stars believed to be members of the studied clusters. Symbols are as in Fig. 1.

A better quantity which may help to understand the properties of such intracluster extinction woud be $\Delta(B-V)$ expressed in units of 'intracluster' optical depth, e.g.

$$\Delta(B-V)' = \frac{\Delta(B-V)}{[E(V-K)]_{\mathrm{ic}}} = \frac{\Delta(B-V)}{E(V-K)-1.28} = \frac{E(B-V)-(1.1/1.3)E(V-K)}{E(V-K)-1.28}.$$

This quantity is shown in Fig. 8 plotted as a function of $E(V-K)$ where all stars with $|E(V-K)-1.28|<0.15$ have been omitted. Although it may not be surprising, the (real) scatter is quite large but the interesting fact is that $\Delta(B-V)' = \Delta(B-V)/[E(V-K)-1.28]$ does not depend on the optical depth but rather varies randomly from place to place within the clusters Tr 14, Tr 16 and Cr 228. The average values of $\Delta(B-V)'$ for each of these clusters are -0.27 ± 0.02, -0.26 ± 0.01 and 0.27 ± 0.04 respectively. It can easily be shown that the quantity $\Delta(B-V)'$ is related to the value of the ratio of total to selective extinction R characteristic of the intracluster medium by:

$$R_{\mathrm{ic}} = 1.1\,\frac{[E(V-K)]_{\mathrm{ic}}}{[E(B-V)]_{\mathrm{ic}}} = \frac{3.08}{2.76\,\Delta(B-V)'+1}.$$

For $\Delta(B-V)' = -0.27$, $R_{\mathrm{ic}} = 12$! Naturally, this quantity, in the present case, cannot be interpreted in the same manner as $R = A_V/E(B-V)$ and this fact merely confirms the idea that the nature of the 'anomalous' extinction is different in the Carina nebula than in the general interstellar medium and dense molecular clouds. Nevertheless, the quantity $\Delta(B-V)'$ may also be applied in a more classical way to the latter regions. In Fig. 9 the results of an identical process to that applied to our sample in Carina are presented for a sample of stars embedded in the Ophiuchus cloud (Chini 1981) and Orion (Breger *et al.* 1981). The values of $\Delta(B-V)'$ are again independent of $E(V-K)$ with averages -0.09 and -0.10 for Ophiuchus and Orion respectively. For Ophiuchus [foreground $E(V-K)=0.14$] this corresponds to $R=4.1$ which is in total agreement with the constant value $R=4.2$ found by Chini (1981); while for Orion [foreground

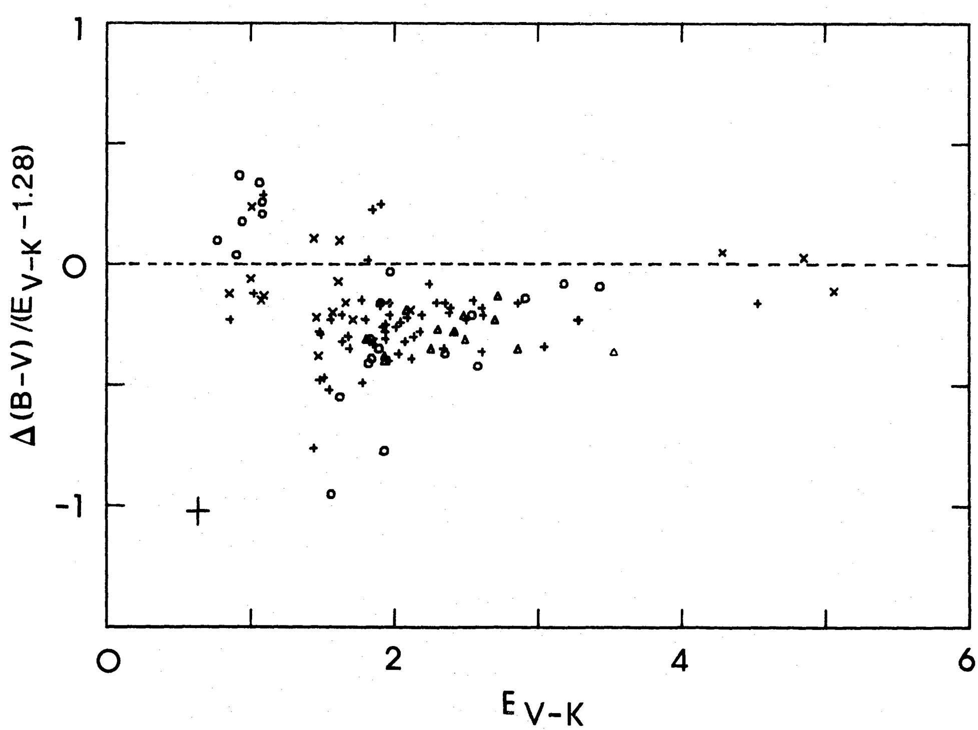

Figure 8. $\Delta(B-V)/[E(V-K)-1.28]$ versus $E(V-K)$ plot for all observed stars believed to be members of the studied clusters. Symbols are as in Fig. 1.

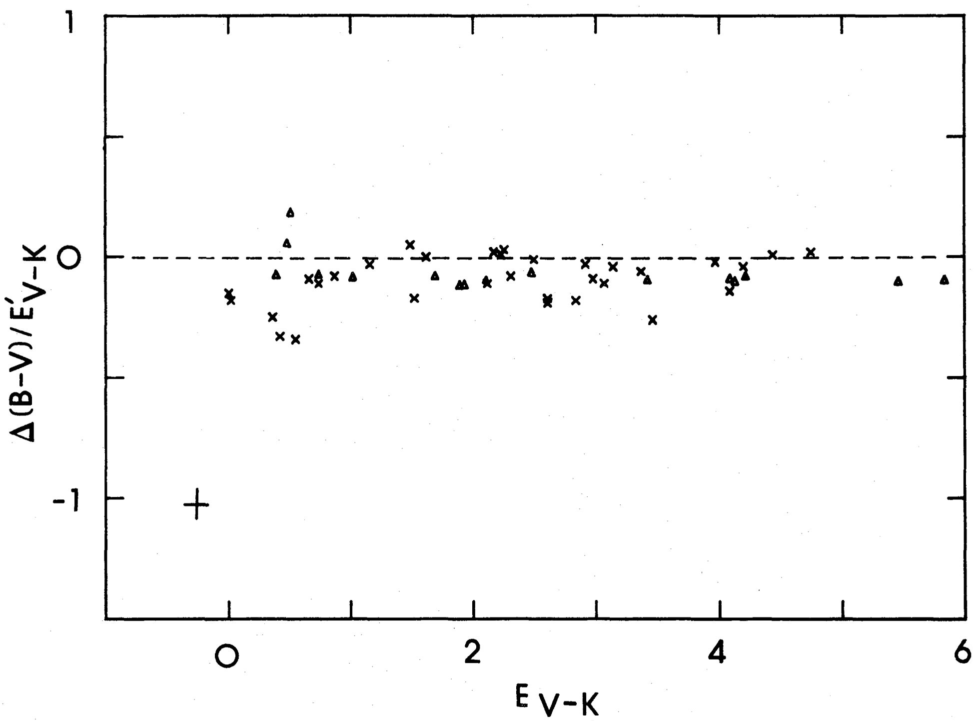

Figure 9. $\Delta(B-V)/E(V-K)'$ versus $E(V-K)$ plot for stars in the (Δ) Ophiuchus (Chini 1981) and ($\times$) Orion (Breger *et al.* 1981) dark clouds. $E(V-K)'$ is defined as $[E(V-K)-0.14]$ for Ophiuchus and as $[E(V-K)-0.20]$ for Orion (see text).

$E(V-K)=0.20]$ the derived value of R is 4.3, a result fully consistent with that of Breger *et al.* (1981).

Seab & Shull (1983) have produced a model of interstellar dust grain processing from modelling a mixture of silicates and graphite (Mathis, Rumpl & Nordsieck 1977) through the passage of a shock wave. They found that significant dust destruction occurs at velocities as small as 40 km s^{-1}. In this model, the collisions destroy more large grains than small and more silicates than graphite. The net effect is that since the large grains absorb more efficiently in this wavelength range, the $E(B-V)$ index will be disproportionally lowered. If the final size distribution were adequate, the result should be like that observed in the Carina clusters. Nevertheless Seab & Shull's present model cannot explain the tendency toward lower values of the interstellar 2200 Å bump which seems to be present in the direction of a few bright stars in Carina (see Aiello *et al.* 1987, 1988). In fact, the model by Seab & Shull predicts the opposite effect. The observations in Carina should, therefore, put some constraints on the final grain size distribution resulting from the shock processing.

The results of a model like that by Seab & Shull (1983) are naturally dependent on the physical parameters of the interstellar material. Small inhomogeneities in the intracluster material would therefore result in large differences in the observed parameters at slightly different positions in the sky, and this fact would be seen as a large scatter in the respective plots. The nova-like star η Carina would naturally be identified with the source of such shocks which 'processed' the intracluster dust grains up to the limits of Cr 228 to the south and not reaching Tr 15 to the north. Further evidence of high-velocity motions of material in the region of the studied clusters comes from optical nebular emission (López & Meaburn 1985) and absorption line studies by Walborn (1982c). In fact, Walborn has found high-velocity (up to 300 km s^{-1}) interstellar absorption components in the direction of stars as far south as Cr 228−65 (HD 93146) and Cr 228−6 (HD 93222) and as far north as HD 93250 in Cr 232.

Table 4. Mean distances and moduli.

Cluster	$E^{C}_{B-V} = 0.36\ E_{V-K}$	$V_0 - M_V$	d (kpc)
Tr15	0.49 ± .09	12.1 ± .2	2.63 ± .24
Tr14	0.82 ± .12	11.9 ± .3	2.40 ± .33
Tr16 + Cr232	0.68 ± .21	12.0 ± .2	2.51 ± .23
Cr228	0.64 ± .26	11.6 ± .4	2.09 ± .38

It seems, therefore, safe to assume a standard extinction law for obtaining the value for the total extinction in the V-band, A_V, from the $V-K$ colour excess index for each cluster and from these obtain some reliable distances to Tr 14, Tr 15, Tr 16/Cr 232 and Cr 228. The results are shown in Table 4 from which we can conclude that all four clusters are located at approximately the same distance from the Sun, but are affected by different amounts of interstellar extinction due to the presence of a 'cloud' of processed dust grains in the vicinity of η Carina.

4.2 INDIVIDUAL STARS WITH PECULIAR INFRARED COLOURS

Surprisingly enough, there seem to be only a few stars in this region with anomalous near-infrared colours. It is surprising because we are dealing with a very large population of O-type stars in a number of open clusters and each of these seems to have quite a different morphology and perhaps age (see e.g. Walborn 1973; Turner & Moffat 1980). We will not discuss the extremely enigmatic η Carinae as this object has been the subject of thousands of written pages and its true nature has not yet been determined. In any case, this object was not observed in the present program.

HD 93131 and HD 93162

These two Wolf–Rayet stars (WR24 and WR25 respectively in the *Sixth Catalogue of Galactic Wolf–Rayet Stars*, van der Hucht *et al.* 1981) have been observed previously in the near-infrared by Williams & Antonopoulou (1981) and Pitault *et al.* (1983). The magnitudes and colours of the present work are in agreement with those of Williams & Antonopoulou for both stars but the *JHKL* photometry given by Pitault and collaborators for HD 93162 is in serious disagreement (more than 1 mag). Since the colour indexes also differ substantially, it is probable that an error in the observation/reduction by Pitault *et al.* (1983) is the cause of this discrepancy rather than the star's variability. HD 93131 and HD 93162 have optical spectra which show O-type absorption line characteristics on top of those of WN7 stars; nevertheless, detailed spectroscopic studies by Moffat & Seggewiss (1978) and Moffat (1978) showed that HD 93131 and HD 93162 are most likely true single stars and that they may be evolving into Wolf–Rayets from being massive Of stars by means of a radiation-pressure-induced stellar wind. Their $K-L$ colour indexes show the presence of excess emission which is similar in both stars and is characteristic of free–free emission from their ionized wind.

Tr 15 – 18 and Tr 16 – 149

These stars are probably the next most conspicuous cases. Their spectral types are O9.5I–II and O4f respectively. Both are reddened by at least 2 mag in excess of that observed in the rest of the clusters to which they belong. No large infrared excesses at $\lambda > 3\,\mu$m are apparent in either of these two stars which have very similar colour excess indexes. The fact that both are O-type stars makes almost certain their membership in Tr 15 and Tr 16. In the case of Tr 16 – 149, it is seen projected against a small patch of heavy obscuration (see e.g. Thé & Groot 1983) and it may be that this star is embedded in this dense and small cloudlet. Tr 15 – 18, on the other hand, does not seem to be associated with an apparent dark cloudlet but in this region the nebulosity is quite faint, and therefore this hypothetical patch of obscuration would be missed due to poor contrast. Nevertheless, a significant excess emission in the L-band is consistent with free–free emission (e.g. Tapia 1981) similar to that observed in HD 93162, HD 93131 (both WN stars) and Cr 228 – 102 which has been neglected in all spectroscopic studies.

Tr14 – 15

This star has received little attention in the past. From *UBV* photometry, a spectral type B7 was determined suggesting that the star may not be a cluster member. Nevertheless the star is conspicuous because it shows the largest infrared excess in our sample. From its $E(V–J)$ colour excess index, a value of $A_V = 2.9$ was computed and a large infrared excess at $\lambda > 2\,\mu$m is clearly present. This excess can only be attributed to warm dust at $T_d \lesssim 1000$ K but with the available data, little more can be said. Spectroscopy in the visual and infrared is needed to understand the evolutionary status of this star. Further evidence on the membership of this star in Tr 14 is also needed.

Tr15 – 28

As pointed out by Feinstein *et al.* (1980), this star is unlikely to be a member of Tr 15 as suggested by the *UBV* data. The $V–K$ colour index is consistent with this interpretation and its spectral type could be later than A0. It is unfortunate that the $H–K$ colour index is probably in error as its position in the $J–H$ versus $H–K$ diagram is hard to understand otherwise.

RT Carina = Tr15 – 16

This is one of the few late-type supergiants in NGC 3372. Again, there is no evidence of it being a member of the cluster. Nevertheless, certain peculiar characteristics of this star (e.g. Forte & Marraco 1986) suggest that RT Carina is a true evolved member of Tr 15.

4.3 THE RATIO OF TOTAL TO SELECTIVE EXTINCTION R

Chini & Krügel (1983) have remarked on the widespread misuse of the parameter $R = A_V/E(B–V)$ which, under 'normal' circumstances, is $R = 1.1\ E(V–K)/E(B–V)$. From a historical point of view, the concept of R was of great importance as the measurement of $E(B–V)$ was the most reliable way of measuring the optical depth of a column of interstellar matter in the direction of a star. In the past, $E(B–V)$ has also been used as a normalization quantity for the majority of studies of the interstellar extinction law and the value of R has been considered to represent a full characterization of the whole optical–infrared extinction law in a given direction of the sky. As Chini & Krugel (1983) have shown, many solutions exist for the grain size distribution (though only a few are realistic) to a given extinction curve. The present results support this conclusion which was also endorsed, based on different analyses, by Clayton, Mathis & Gardelli (1986). In conclusion, the parameter R (as defined above) should be used with care as there have proved to be many cases where R cannot be considered as a characteristic value of the whole extinction curve.

5 Comparison with a recent near-infrared study of the region

Very recently, Smith (1987) published the results of an infrared study of the brightest stars at 2.2 μm in order to search for and identify possible highly reddened members of the clusters Tr 14 and Tr 16 embedded in dense parts of the molecular cloud. He surveyed, in the K photometric band, 324 arcmin^2 and performed JHK photometry of 79 of the 93 stellar sources detected, 32 of which were optically visible cluster members. From the latter set, 24 stars are in common with the work presented here and no systematic differences were found in the photometry. After transforming Smith's magnitudes (in the AAO system) into the CTIO/CIT system using the relations by Elias *et al.* (1983), the final mean residuals (Smith's minus present photometry) were found to be $\Delta K = 0.00 \pm 0.07$ (s.d.), $\Delta(J-K) = +0.01 \pm 0.02$ (s.d.) and $\Delta(H-K) = +0.03 \pm 0.04$ (s.d.).

Smith divided his IR-brightness-selected sample into two main categories, namely, those stars of an early type (O and B), presumably members of Tr 14 and Tr 16, and those of a later spectral type, most probably field stars. The few newly-discovered early-type stars were very faint (or invisible) on photographic plates and had avoided classification as probable cluster members. On the other hand, most of the field stars appeared to be highly obscured background objects and were found to follow a normal reddening law in the 1–3 μm region, in agreement with Tapia (1981). Nevertheless, a few of the most highly obscured stars seemed to deviate considerably from the average. When mapping the total obscuration (i.e. dust column density) toward the background stars, Smith found that the contours followed the dark lane to the south-west of Tr 16 but curved northwards in the direction of the centre of Tr 14. This behaviour, also found with CO absorption observations by de Graauw *et al.* (1981), suggests that the obscuring cloud lies *in front* of the south and south-west section of the Tr 16 ionization region, but in the north-west section, the densest absorbing material is located *behind* the Tr 14 cluster.

Finally, for a sample of 21 O and B stars with available spectral classifications, Smith (1987) also computed average colour indices in complete agreement with those presented here, although he made no distinction between clusters. He obtained an average value of $R = 1.1\, E(V-K)/E(B-V) = 4.8$ without attempting to separate foreground and intracluster extinction. Smith also concluded that the anomalous extinction is present only when the extinction curve is normalized to $E(B-V)$.

6 Conclusions

From the present $JHKL$ photometry of more than 200 stars located within the limits of the open clusters Tr 14, Tr 15, Tr 16, Cr 228 combined with the available visual photometry and spectroscopy, the following main conclusions were derived.

(i) The colour excess ratios for the stars in all clusters are constant and resemble the 'standard' extinction law except those involving $E(B-V)$ in Tr 14, Tr 16 and Cr 228 implying that for $\lambda > 0.55\,\mu$m the extinction law in Carina is similar to that of the general diffuse interstellar medium, which in turn suggests that the particle size distribution of a fraction of larger grains are the same (*cf.* Mathis 1986). The colour-excess anomalies reported here show no correlation whatsoever with the spectral type or presence (absence) of emission-line spectra.

(ii) The anomalies in the UB-bands are interpreted as follows: The interstellar extinction is 'normal' up to a value of $A_V \simeq 1.4$, which is caused by foreground material. Starting at that optical depth, where Tr 15 is located, a denser intracluster dust cloud is detected whose grains have been 'processed' in such a way as to produce disproportionally lower $B-V$ excess per unit column density as compared to the average interstellar medium.

(iii) This processing may be explained by a model of the pass of a shock wave, presumably originating in η Carinae, which changes the grain abundances and size distribution in the nearby interstellar medium in a way similar to that proposed by Seab & Shull (1983).

(iv) The distance to Tr 14, Tr 15, Tr 16/Cr 232 and Cr 228 is 2.4 ± 0.2 kpc and the total amount of reddening varies considerably from cluster to cluster.

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