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# Dust properties in the direction of Trumpler 37

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**Abstract.** The fourteen brightest OB stars of the Trumpler 37 Cluster have been observed in the $V, R, I, J, H, K$ photometric bands. These have been used to derive accurate measurements of the quantity $R_V = A_V/E(B-V)$. Different from previous studies it is found that $< R_V >$ in Trumpler 37 is close to the mean interstellar value of 3.1. Most of the reddening towards Trumpler 37 is found to be of foreground origin. This is consistent with the lack of variations, observed by us, of $R_V$ with the projected distance from the center of the cluster. In two highly reddened stars of the cluster, whose reddening is certainly mostly local, the observed $R_V$ is lower than the mean interstellar value of 3.1. This is to be compared with the behaviour of the Trapezium stars in Orion, whose $R_V$ is quite above such value whereas the age of the cluster is similar to the one of Trumpler 37.

**Key words:** clusters: open, and associations – Interstellar medium: extinction

## 1. Introduction

Earlier efforts to separate the dust properties in different lines of sight in the Galaxy according to the physical state of the intervening interstellar medium (Mathis & Cardelli, 1992; Cardelli & Clayton, 1988; Martin & Whittet, 1990; Snow et al., 1990; Cardelli & Clayton, 1991; Snow et al., 1994) have been put on a more quantitative basis in a recent work by Barbaro et al. (1997).

Making use of an extended critical data base containing all the available information on the $N(H_2)$ and $N(HI)$ column densities towards OB stars, together with the best determinations of the $R_V$ parameter in the same line of sight, a statistical study allowed the authors to classify the lines of sight in four classes. According to the physical state of the associated gas, the lines of sight have been classified in those dominated by only one of the following hydrogen states ($H_2$, $HI$, $HII$) or those where at least two of these states are of comparable importance. In the first three classes, going from the $H_2$ to $HII$ regions, $< R_V >$ has been found to be 2.96 $\pm$ 0.24, 3.64 $\pm$ 0.40 and 4.76 $\pm$ 0.80, respectively, showing a continuity in the dust properties. This is certainly of great importance for the nature and evolution of dust grains, from the phases of molecular clouds to the $HII$ regions.

However the number of galactic lines of sight where all the quantities needed are available, was quite limited. We have then decided to contribute the subject by observations in many directions both in open clusters/association and in the general field. In the next Sections we deal with the observational strategy (Sect. 2), the photometric observations in Trumpler 37 and the derivation of $R_V$ in this cluster (Sect. 3). A discussion follows in the last Section.

## 2. Strategy of the planned observations

Relevant quantities are column densities $N(H_2)$, $N(HI)$, $N(HII)$, and photometric data to determine $R_V$. The first two column densities are obtained from absorption lines around 1100 Å and from $Ly_\alpha$. As with the $H_2$ molecular lines we are presently limited to about 200 stars (Savage et al, 1977) observed by the Copernicus satellite.

The determination of the $H(II)$ column densities requires either radio free-free observations of high spatial resolution or optical observations of hydrogen recombination emission lines, which are hardly available. It is however possible to derive $N(HII)$ by modeling the $HII$ regions around the exciting target star on the basis of the Strömgren theory (1939), with reasonable assumptions on the average density. This requires that the only $HII$ region crossed by the line of sight is the one of this star. As with the determination of $R_V$ one can extrapolate the UV extinction curve, secured for instance by the IUE satellite, to the IR domain. Another procedure requires the photometric measurements of the target stars from the optical to the near IR. We consider that this last method has two important advantages: (i) it is free from any "anomaly" or "individuality" of the extinction curve in the far UV, a spectral region known to be quite

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**Table 1.** Photometric results for Trumpler 37

| N | Star | V | R | I | J | H | K | Sp type | E(B-V) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | HD 239683 | 9.29 | 8.94 | 8.80 | 8.76 | 8.70 | 8.68 | B3IV | 0.48 |
| 2 | HD 205794 | 8.42 | 7.97 | 7.74 | 7.58 | 7.50 | 7.45 | B0.5V | 0.61 |
| 3 | HD 205948 | 8.60 | 8.27 | 8.13 | 8.08 | 8.04 | 8.02 | B1V | 0.51 |
| 4 | HD 239722 | 9.56 | 9.08 | 8.52 | 8.34 | 8.08 | 7.95 | B2IV | 0.90 |
| 5 | HD 206267 | 5.62 | | | 5.30 | 5.25 | 5.25 | O6V | 0.52 |
| 6 | HD 239748 | 8.75 | | | 8.46 | 8.43 | 8.47 | B1V | 0.42 |
| 7 | HD 239742 | 9.41 | | | 8.96 | 8.95 | 8.97 | B2V | 0.44 |
| 8 | HD 239745 | 8.92 | | | 8.40 | 8.35 | 8.37 | B1V | 0.50 |
| 9 | HD 239689 | 8.82 | 8.53 | 8.48 | 8.51 | 8.50 | 8.52 | B1.5V | 0.42 |
| 10 | HD 239693 | 9.50 | 9.20 | 9.08 | 9.01 | 8.94 | 8.92 | B3V | 0.42 |
| 11 | HD 239724 | 9.12 | 8.66 | 8.42 | 8.21 | 8.11 | 8.08 | B1III | 0.63 |
| 12 | HD 239729 | 8.34 | 7.88 | 7.67 | 7.55 | 7.46 | 7.41 | B0V | 0.67 |
| 13 | HD 239725 | 9.10 | 8.75 | 8.64 | 8.62 | 8.55 | 8.55 | B2.5V | 0.46 |
| 14 | HD 204827 | 7.93 | 7.24 | 6.75 | 6.48 | 6.32 | 6.26 | O9.5V | 1.10 |
| 15 | HD 239710 | 9.49 | | | 8.74 | 8.68 | 8.68 | B2.5IV | 0.54 |
| 16 | HD 239738 | 8.59 | | | 7.98 | 7.95 | 7.95 | B2IV | 0.50 |
| 17 | BD +57 2395B | 10.08 | | | 9.15 | 8.99 | 8.94 | B3V | 0.68 |

The photometry of stars 15, 16, 17 and V of stars 5, 6, 7, 8 are from Roth (1988), as well as the spectral types and $E(B-V)$. The number in the first column identifies the stars in Fig. 1

sensitive to the grain properties, and (ii) it allows to obtain data on many more stars than those for which the extinction curve in the far UV has been measured (also considering that the IUE satellite is no longer available).

On this framework we have decided to contribute observations to obtain accurate $R_V$ values, via extended photometric measurements.

The Trumpler 37 open cluster consists of stars with particularly low $R_V$ values. Their extinction properties have been studied by Clayton & Fitzpatrick (1987) and Roth (1988). The first authors have studied the extinction curves in 18 stars of the cluster with the IUE satellite, finding a far UV rising branch higher than that of the mean interstellar extinction curve. Roth (1988) has extended the study of the extinction in Trumpler 37 by adding $J$, $H$, $K$ photometric observations which allowed to derive a mean value of $R_V$ = 2.82 $\pm$ 0.15. The author however neither provides the individual $R_V$ pertaining to the different stars, something which is instead important to our final goals above specified, nor makes use of the available photometric data apart $K$, which are important for a more precise determination of $R_V$. We then considered useful to obtain new observations of stars in this important cluster, covering the full range $V$, $R$, $I$, $J$, $H$, $K$, in order to secure a good determination of $R_V$ with the method considered more reliable.

## 3. Photometric observation of Trumpler 37

Trumpler 37 is an open cluster in the central region of the Cepheus OB2 association. It is associated to the $HII$ region IC 1396. The number of known members of Trumpler 37 amount to about 500 stars. The age of the cluster is estimated to be $2-4$ $10^6$ years and the distance module 9.9 mag (Marshall & van Altena, 1987).

**Table 2.** Extinction parameters for Trumpler 37

| N | Star | $A_V$ | $R_V$ |
|---|---|---|---|
| 1 | HD 239683 | 1.40±0.09 | 2.91±0.31 |
| 2 | HD 205794 | 2.10±0.05 | 3.43±0.20 |
| 3 | HD 205948 | 1.59±0.05 | 3.11±0.22 |
| 4 | HD 239722 | 2.59±0.13 | 2.87±0.21 |
| 5 | HD 206267 | 1.49±0.28 | 2.86±0.65 |
| 6 | HD 239748 | 1.23±0.37 | 2.92±1.01 |
| 7 | HD 239742 | 1.37±0.30 | 3.10±0.81 |
| 8 | HD 239745 | 1.53±0.36 | 3.05±0.85 |
| 9 | HD 239689 | 1.26±0.09 | 2.99±0.36 |
| 10 | HD 239693 | 1.35±0.06 | 3.20±0.29 |
| 11 | HD 239724 | 2.11±0.07 | 3.34±0.21 |
| 12 | HD 239729 | 2.11±0.07 | 3.14±0.19 |
| 13 | HD 239725 | 1.48±0.09 | 3.21±0.34 |
| 14 | HD 204827 | 3.03±0.12 | 2.75±0.16 |
| 15 | HD 239710 | 1.79±0.32 | 3.31±0.71 |
| 16 | HD 239738 | 1.59±0.28 | 3.17±0.68 |
| 17 | BD +57 2395B | 1.98±0.32 | 2.90±0.56 |

The number in the first column identifies the stars in Fig. 1

Using the German 1.23 m telescope of Calar Alto Observatory (Spain) equipped with a NICMOS 256x256 near-IR camera (MAGIC) and a 1024x1024 CCD camera (TEK#6), we have observed a total of 14 early type stars (spectral types from O6 to B8) and magnitudes spanning from $m_V$ = 5.62 to $m_V$ = 10.46.

In the case of MAGIC observations for each star we took a mosaic of five images. The first with the star at the center of the detector and the other four with the star moved to the center of each quadrant of it. This technique works well, permitting to combine on the same frame star and sky measurements with no penalty in observing time. The flat field frame has been produced taking exposures (in the three filters) of a uniformly illuminated part of the dome. The data reduction has been performed in

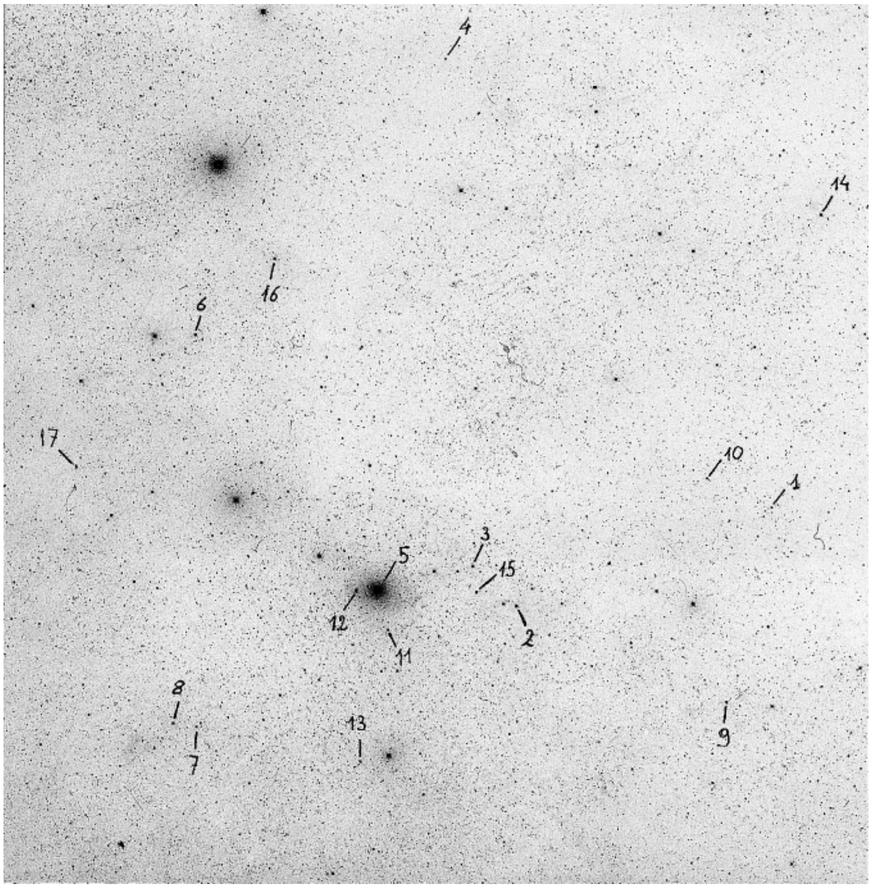


**Fig. 1.** Trumpler 37 region. The star observed for this study are identified. The numbers are reported in Table 1

**Table 3.** Photometry of Orion nebula cluster

| HD or BD | Parenago | V | R | I | J | H | K | Sp type | E(B-V) |
|---|---|---|---|---|---|---|---|---|---|
| 36629 | 1044 | 7.65 | 7.53 | 7.53 | 7.54 | 7.56 | 7.67 | B2.5IV | 0.24 |
| 30958 | 1708 | 7.32 | 7.28 | 7.36 | 7.39 | 7.40 | 7.44 | B3V | 0.10 |
| 36992 | 1772 | 8.43 | 8.19 | 7.98 | 7.70 | 7.50 | 7.32 | B2V | 0.34 |
| 294264 | 1798 | 9.51 | 9.02 | 8.57 | 8.37 | 8.06 | 7.80 | B3Vn | 0.58 |
| 37021 | 1863 | 7.96 | | | 5.63 | 5.33 | 5.35 | B3V | 0.44 |
| 37020 | 1865 | 6.72 | 6.41 | 6.20 | 4.80 | 4.61 | 4.73 | O7V | 0.32 |
| 37023 | 1889 | 6.70 | 6.39 | 6.19 | 5.95 | 5.83 | 5.62 | B0.5V | 0.36 |
| 37022 | 1891 | 5.13 | 4.91 | 4.73 | 4.51 | 4.33 | 4.18 | O6V | 0.32 |
| -05 1318 | 1956 | 9.71 | 9.35 | 8.81 | 7.86 | 7.34 | 7.05 | B2V | 0.51 |
| 37041 | 1993 | 5.07 | 4.98 | 4.98 | 4.78 | 4.83 | 4.86 | O9V | 0.22 |
| 37061 | 2074 | 6.80 | 6.41 | 6.10 | 5.76 | 5.58 | 5.51 | B0.5V | 0.55 |
| | 2248 | 11.40 | 10.45 | 9.63 | 8.93 | 8.43 | 8.10 | B9V | 0.70 |
| 37130 | 2302 | 9.97 | 9.73 | 9.52 | 9.38 | 9.27 | 9.23 | B9V | 0.18 |
| | 2425 | 10.67 | 9.72 | 9.09 | 8.77 | 8.32 | 8.16 | B6V | 0.85 |

the following way. First the image has been cleaned of the bad pixels, then a sky frame has been constructed calculating the median of the five exposures. On each of the five images of the mosaic we applied sky subtraction and flat fielding and, over the resulting frames, we performed aperture photometry of our target. Finally the calibration with a standard star has been applied. The five derived values have been then averaged and a standard deviation has been obtained. When this deviation was larger than 0.03 mag, indicating that some problem occurred during the measurements, the whole mosaic has been disregarded.

In the case of the CCD observations, flat field images have been obtained by taking exposures on the sky during twilight.

The errors in the $J$, $H$, $K$ photometry are of the order of 0.02-0.03 mag, while in the $V$, $R$, $I$ photometry the errors are around 0.01-0.02 mag.

The resulting photometric data are reported in Table 1. The first column of this Table contains a progressive number used to identify stars in Fig. 1 obtained at the Asiago Astrophysical Observatory with a Schmidt Telescope (original scale of 206 arcsec/mm)

**Table 4.** Extinction parameters for Orion Nebula cluster

| HD or BD | Parenago | $A_V$ | $R_V$ |
|---|---|---|---|
| 36629 | 1044 | 0.88±0.09 | 3.65±0.69 |
| 30958 | 1708 | 0.55±0.07 | 5.45±1.82 |
| 36992 | 1772 | 1.90±0.31 | 5.57±1.24 |
| 294264 | 1798 | 2.44±0.32 | 4.20±0.54 |
| 37021 | 1863 | 3.78±1.03 | 8.60±2.74 |
| 37020 | 1865 | 3.29±0.87 | 10.30±3.38 |
| 37023 | 1889 | 2.05±0.23 | 5.68±0.96 |
| 37022 | 1891 | 1.98±0.25 | 6.17±1.17 |
| -05 1318 | 1956 | 3.46±0.78 | 6.79±1.80 |
| 37041 | 1993 | 1.31±0.17 | 5.93±1.33 |
| 37061 | 2074 | 2.39±0.20 | 4.34±0.51 |
| | 2248 | 3.73±0.20 | 5.34±0.43 |
| 37130 | 2302 | 0.98±0.04 | 5.42±0.80 |
| | 2425 | 3.28±0.24 | 3.86±0.38 |

From the observed IR fluxes, the colour excesses $E(\lambda - V)$ have been found using the intrinsic colours by Johnson (1966). These colours result more homogeneous than corresponding data by more recent authors, as explained, e.g., by Cardelli et al. (1988).

The quantity $A_V$ has then been determined with a least square solution, by fitting (Cardelli et al., 1989):

$$E(\lambda - V) = A_V[R_L(\lambda) - 1] \quad (1)$$

where $\lambda = R, I, J, H, K$ and $R_L$ is the extinction curve $A_\lambda/A_V$ by Rieke & Lebofsky (1985). Since the fitting expression (1) is a homogeneous equation, the uncertainty of each $A_V$ has been calculated considering that we have N–1 degrees of freedom. N is the number of the photometric bands used. From the derived $A_V$ and the known $E(B - V)$ we finally obtain $R_V$. From the mentioned uncertainty of $A_V$ only a lower limit to the accuracy of $R_V$ can be derived. This because of the uncertainties introduced by inaccuracy in the spectral types and consequently in the adopted intrisic colour. Anyhow an estimate of the accuracy of the deduced $R_V$ has been done. Our final adopted $R_V$ values and their errors are reported in Table 2.

Our mean $R_V$ equals 3.08±0.15 while Roth has 2.82±0.15. If we repeat the analysis made by Roth with our $K$ values we obtain $2.85 \pm 0.17$ well in agreement with him.

## 4. Discussion

The individual $R_V$ values we have obtained are generally a little larger than those obtained by Roth (1988). He derived $R_V$ values using only the photometric point $K$ and the formula $R_V = 1.1E(V-K)/E(B-V)$ taken from Whittet & van Breda (1978). The value of 3.08 is closer to the mean interstellar value (3.1) than the number found by Roth. Thus our results no longer support Trumpler 37 as a case of anomalous reddening.

We find interesting to examine whether there is any dependence of $R_V$ on the projected radial distance from HD 206267, which represents the center of both the cluster and the associated $HII$ region. This in order to compare with the behavior of $R_V$ in the Orion Nebula cluster and its $HII$ region, which has a similar age (4 $10^6$ yr, Meynet et al., 1993). To do that we have first calculated the $R_V$ values in the Orion Nebula cluster making use of the same technique we employed for Trumpler 37. The results are reported in Table 4. We have used to this purpose the $B, V, R, I$ photometric data of Lee (1968) and the $J, H, K$ of Qian & Sagar (1994). These data are reported in Table 3. In Fig. 2 we show the behavior of $R_V$ as function of the projected distance from the center for both clusters.

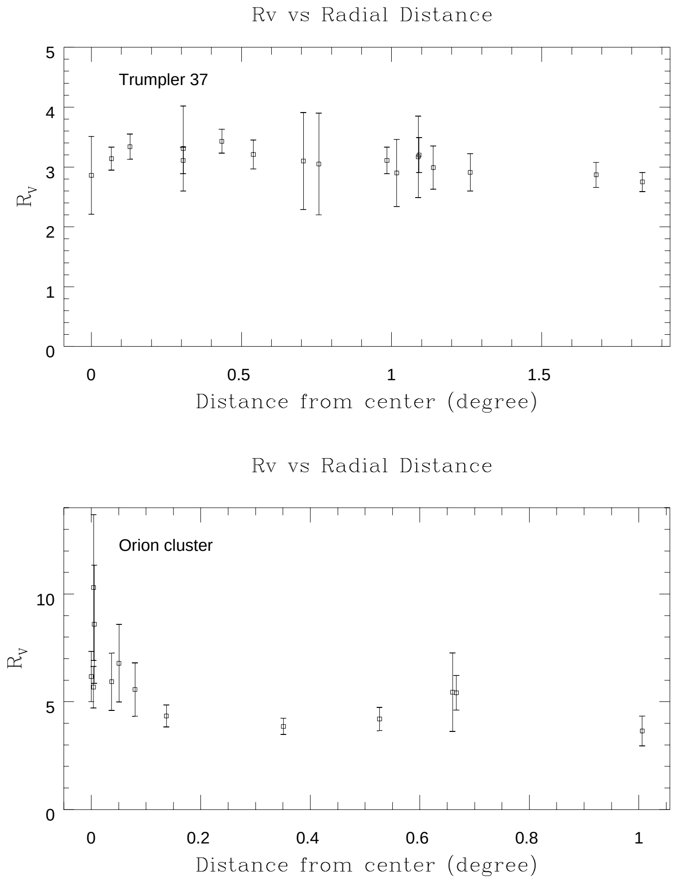


**Fig. 2.** Comparison of $R_V$ in the Orion Cluster and in Trumpler 37

While in the case of the Orion cluster the $R_V$ reaches quite an high value close to the Trapezium and fades out in the outer part of the Nebula to values around 4, in Trumpler 37 $R_V$ is almost constant and close to the mean interstellar $R_V$ throughout the whole cluster.

We underline that the two most reddened stars at the edge of Trumpler 37, HD 204827 and HD 239722 also from our analysis have low $R_V$ values of $2.75 \pm 0.16$ and $2.87 \pm 0.21$, respectively, which qualify them as two highly reddened galactic OB stars that at the same time have a low $R_V$ value.

The different behaviour in these young clusters of similar age arises the question on the different nature of the responsible grains. A first possibility is that the low surface brightness of the IC 1396 $HII$ region associated with Trumpler 37 cluster may be related with a low amount of dust in the cluster, in comparison with the foreground dust belonging to the general interstellar medium. A foreground $E(B-V)$ = 0.4 (Clayton & Fitzpatrick, 1987) found in Trumpler 37 is much greater than the foreground $E(B-V)$ = 0.05 seen towards the Orion cluster (cf. Breger et al., 1981). The average $R_V$ we observe in Trumpler 37 is consistent with the fact that the observed dust is dominated by the interstellar component. This leaves open the possibility that the internal dust has a different $R_V$, either higher or lower.

If the two most reddened stars at the edge of the cluster are representative of the dust in the whole region, we must conclude that two young clusters with very similar age have dust with $R_V$ quite separated above and below the value of the mean interstellar medium. Because their ages are comparable with the lifetime of massive OB stars we may tentatively suggest that in the two cases a different number of supernova explosions might have occurred.

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