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Young stellar objects and abnormal extinction within M 17

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Abstract. The stellar content of M 17 is investigated by photoelectric observations from 1.2 to 4.8 μm for 69 stars. Combining these data with previous $UBVRI$ measurements we obtain the following results: i) 32 stars are visible objects on B and V plates reaching to $\sim$ 20.1 and 18.2 mag, respectively; the remaining 37 stars are pure IR sources with $K < 12.2$ mag. ii) In various two-colour-diagrams 18 of the visible stars can uniquely be identified as early type members of the young stellar cluster, suffering between 6 and 18 mag of visual extinction. Their colours suggest a special reddening law within M 17, characterized by R = 4.8. iii) 28 of the new IR sources can also be classified as B-type stars with up to 50 mag of visual extinction. iv) The major result, however, is the discovery of a strong IR excess associated with 20 stars (11 visible + 9 IR objects). Their spectral energy distributions resemble those of five previously detected "*cocoon stars*" in M 17 and thus qualifies them as Class I sources. The observed luminosity of these new IR excess objects is more than 60 times larger than that found for the classical Class I sources in Ophiuchus. We therefore suggest them to be the high mass counterparts of this early evolutionary stage. They represent the youngest generation of massive early type stars in M 17 still surrounded by relicts of their protostellar clouds. The comparatively low visual extinction of only $6 < A_V < 27$ mag is probably a consequence of the strong radiation field from neighbouring O stars which has partly cleared the region.

The influence of interstellar extinction on the spectral index $\alpha_{\rm IR}$ between 2.2 and 20 μm, often used to determine the evolutionary stage of young stellar objects, is discussed. In the case of deeply embedded objects ($A_V > 40$ mag) and wavelengths below 10 μm $\alpha_{\rm IR}$ may be dominated by interstellar extinction rather than circumstellar emission. A reasonable alternative in the absence of data longward of 4.8 μm are certain IR-colour relations which provide limits to detect IR-excess objects independent of the amount of extinction. We find empirical colour criteria of the form $(K - L) > 0.26(J - K) + 0.25$ and/or $(K - M) > 0.37(J - K) + 0.80$ that may trace Class I objects reliably.

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1. Introduction

One of the most luminous HII regions in the Galaxy is M 17 with $L_{\rm bol} \sim 10^7\,{\rm L}_\odot$ at a distance of 2.2 kpc. The stellar content of M 17 and in particular its ionizing sources were a puzzle for many decades and have been the subject of several investigations. Due to the large amount of visual extinction only two OB stars, associated with the optical nebula could be identified by Schulte (1956), although the number of Lyman-continuum photons of 2.9 10^{50} s^{-1} (Felli et al. 1984) requires about 6 early O-type stars. Beetz et al. (1976) found an embedded star cluster by imaging the highly obscured SW region of the optical nebula at 0.92 μm; the location of this star cluster was coincident with the peak of IR and radio emission. Chini et al. (1980, hereafter CEN) investigated the cluster members by *UBVRI* photometry and found sufficient early type stars to account for the IR- and Lyman-continuum flux. Recently, the problem of ionizing sources was re-addressed by Hanson & Conti (1995) by means of K-band spectroscopy; the number of early O-type stars identified in that study also matches well the observed Lyman-continuum flux. Therefore, the excitation problem of M 17 can be regarded as solved.

The *UBVRI* photometry by CEN indicated an abnormal extinction law within M 17. Subsequent NIR photometry by Chini & Krügel (1983, hereafter CK1) showed that the ratio of total to selective extinction $R = A_V/E_{B-V}$ was $\sim$ 4.9. Likewise, these NIR studies revealed the presence of a number of IR excess candidates whose spectral energy distributions (SEDs) rise steeply until 20 μm, suggesting the presence of circumstellar dust (Chini 1982, Chini & Krügel 1985, hereafter CK2). *JHK* imaging of the cluster field by Lada et al. (1991) corroborated the finding that the IR colours of many cluster members are not consistent with purely reddened stellar photospheres but may be due to circumstellar emission. We have started a longterm IR study using photoelectric and CCD techniques from 1.2 to 20 μm to re-address the problem of abnormal reddening and to investigate the nature of IR excess objects in M 17. The present

Table 1. Photometry of visible stars in M 17

CEN	RA	Dec	U	B	V	R	I	J	H	K	L	M
	[1950]											
17	18 17 28.2	−16 13 06	16.27	16.02	14.96	14.16	13.52	12.88	12.42	12.18		
10	28.9	10 12	15.50	13.40	11.68	10.15	8.80	8.06	7.10	6.88	6.68	6.31
16	29.6	9 58	15.03	14.99	13.69	12.05	10.95	9.93	9.22	8.90	8.68	9.05
22	30.7	11 23	16.07	15.78	14.81	13.89	13.30	12.48	11.76	11.33	11.02	
32	31.3	11 18		18.1	17.4	16.2	15.5		12.12	10.55	9.36	
36	32.1	11 04		20.8	18.2	16.5	14.0	12.75	11.47	11.00	10.57	
49	32.1	11 40		18.4	17.1	15.2	13.4	12.17	10.74	9.60	8.40	7.27
57	32.3	12 38		18.0	15.9	13.8	11.6	10.65	9.61	8.98	8.38	7.78
14	32.7	12 16	16.12	15.57	14.53	13.19	12.36	12.26	11.91	11.32	10.67	
18	32.7	09 56	16.39	15.87	14.20	12.07	10.35	9.14	8.24	7.85	7.55	7.24
26	32.9	12 28	17.62	17.11	15.74	14.17	12.82	11.90	11.28	10.66	9.59	
48	33.0	11 38	17.43	16.90	15.44	13.75	12.75	11.65	10.81	10.41	10.18	
40	33.0	10 43		20.2	18.3	16.2	13.8	12.36	11.45	10.93	9.83	
52	33.3	11 44		18.7	17.4	15.7	14.0		12.60	11.21	9.74	
51	33.4	11 26		19.1	17.8	16.1	13.8	12.58	10.94	9.60	8.23	6.95
41	34.3	11 35		19.7	18.0	16.4	13.8	12.82	12.07	11.49	11.27	
0	34.4	13 24	13.24	11.23	9.61	8.39	7.50	6.88	5.95	5.78	5.67	5.51
46	34.6	12 25		19.0	17.6	15.6	13.1	12.45	11.19	9.70	8.44	7.11
65	34.8	12 22		18.2	16.8	14.8	12.8	13.08	11.75	10.67	9.56	
30	35.5	10 47		19.0	17.7	15.7	13.5	12.09	11.10	10.69	10.24	
55	36.0	12 17		19.8	18.0	16.2	14.6	12.22	11.10	10.66	10.11	
42	36.0	12 33		17.89	16.12	14.17	13.52	11.81	10.88	10.22	10.01	
59	36.2	12 19		19.5	17.7	15.8	14.3	12.11	10.91	10.37	10.04	
1	36.7	12 08	17.04	16.28	14.13	11.50	9.21	7.55	6.41	5.84	5.53	5.02
27	36.7	13 01		19.7	17.9	15.8	13.2	11.27	10.07	9.59	8.93	
61	37.0	11 55		19.4	17.4	15.3	13.3	11.43	10.12	9.49	9.16	
44	37.3	11 28	17.63	16.89	15.28		13.17	13.83	12.80	12.44		
25	37.7	11 29	17.44	16.85	15.41	13.74	12.08	10.38	9.36	9.12	8.93	
28	38.7	13 02	16.56	16.58	15.56	14.10	12.96	12.67	12.08	11.63	10.77	
29	39.9	11 34		19.9	17.9	16.0	13.7	11.91	10.83	10.33	10.02	
2	41.4	11 33	12.18	12.17	11.03	9.81	8.91	8.28	7.67	7.45	7.26	6.57
3	42..2	12 12	10.44	10.71	9.92	8.95	8.43	8.32	7.89	7.71	7.32	

Notes to Table 1: The $UBVRI$ data are taken from CEN, the $JHKLM$ data are from the present work.

paper describes the results from the photoelectric studies at 1.2 to 4.8 μm. We concentrate on the derivation of the abnormal extinction law and on the identification of new IR excess sources. In a subsequent paper we will discuss the SEDs of these IR sources by means of photometry from 1.2 to 20 μm and CCD data at JHK from different epochs.

2. Observations

The $JHKLM$ data were obtained at the 1.9 m telescope of the South African Astronomical Observatory (SAAO) in Sutherland during June 1992 and October 1995. We scanned an area of about $4'$ x $4'$ at K with a $12''$ aperture, thus covering the entire cluster field investigated by CEN. 69 sources brighter than $K \sim 12.2$ mag were found and subsequently observed at $JHKLM$; the "*cocoon stars*" found by CK2 were also remeasured but their photometry is discussed elsewhere (Chini et al. in prep., hereafter CKC). We used the facility IR photometer (Mk III) and standard reduction methods; calibration stars were taken from the lists of Koornneef (1983a) and Glass (1974). The photometric results are summarized in Tables 1 and 2 together with the positions of the stars. These were determined from the I-band plates of CEN and from our K-band CCD frames (CKC); the positional accuracy is better than $1''$. For reasons of clarity we have devided the sample into "*visible stars*" (designation: CEN) and "*IR sources*" (designation: IRS) to distinguish between those stars visible on the B and V-plates of CEN and newly discovered IR sources, 9 of which are, however, also present on the R and I-plates of CEN.

For the photometry we used apertures of $6''$ and $9''$; the chopper throw was selected for each star separately by checking on the I-plates of CEN that the reference position did not contain further stars. Depending on the brightness of the objects, the photometric accuracy is about 0.05 - 0.10 mag at JHK and 0.10 - 0.20 mag at L and M as estimated from repeated measurements for some of the stars. Table 1 contains 11 stars (CEN 1, 2, 3, 14, 16, 18, 26, 27, 40, 57, 61) which have been observed pre-

Table 2. Photometry of IR sources in M 17

IRS	*RA* [1950]	*Dec*	*V*	*R*	*I*	*J*	*H*	*K*	*L*	*M*	**CEN**
1	18 17 28.2	−16 12 06	> 18.2	18.2	15.1	13.10	10.57	9.11	7.53	6.24	93
2	28.5	12 41	> 18.2	17.9	14.1	11.53	9.75	8.80	7.59	6.33	92
3	29.3	10 32			> 16.5	13.53	10.10	8.75	7.75	7.13	
4	30.9	8 52		> 18.2	16.2	12.64	9.60	8.05	6.98	6.82	
5	31.5	13 03			> 16.5	13.91	10.54	9.14	7.60	6.15	
6	31.7	10 19			> 16.5	15.60	11.85	10.29	9.06		
7	31.7	11 55			> 16.5	14.55	11.34	9.42	8.42	7.09	
8	32.4	10 21	> 18.2	17.3	13.9	10.83	8.29	7.38	6.53	5.77	95
9	33.1	10 12			> 16.5	13.10	11.70	10.19	9.00	7.50	
10	33.2	13 00			> 16.5	13.89	11.70	10.53	9.19		
11	33.7	11 47			> 16.5		13.00	10.73	9.25		
12	33.8	12 45			> 16.5	14.31	11.47	9.87	8.50	7.71	
13	34.5	12 38		> 18.2	16.0	13.50	12.12	11.14	10.87		
14	34.9	11 30			> 16.5		14.35	11.43	9.88		
15	35.5	13 35				11.23	10.50	10.27	9.43		
16	35.7	12 07	> 18.2	17.5	14.3	13.09	11.46	10.55	10.25		84
17	35.8	10 40			> 16.5	14.01	11.39	9.67	8.38	7.44	
18	36.0	11 06	> 18.2	17.9	14.4	12.28	10.78	10.36	9.89		97
19	36.2	11 02		17.9	> 14.4	12.25	11.01	10.34	10.16		96
20	37.1	11 38			> 16.5		13.49	11.47	9.67	8.06	
21	37.3	12 16	> 18.2	16.4	12.9	10.18	8.45	7.69	7.03	6.40	37
22	37.6	12 25			> 16.5		12.35	9.84	8.42	6.67	
23	37.8	11 56	> 18.2	> 18.2	16.2	12.55	10.45	9.13	7.72	6.55	
24	37.9	13 21			> 16.5	15.98	12.78	10.80	9.25		
25	37.9	10 50	> 18.2	17.5	14.2	12.25	11.11	10.43	9.82		100
26	38.5	11 09	> 18.2	17.5	14.4	13.58	12.05	11.57	11.41		99
27	38.2	12 45			> 16.5	14.61	11.95	10.92	10.69		
28	38.7	10 41			> 16.5	14.10	12.08	10.64	9.72		
29	39.4	11 04			> 16.5		13.25	11.21	10.50		
30	39.6	13 09		> 18.2	16.2		11.96	11.19	10.37		
31	39.8	12 35			> 16.5		13.84	11.18	9.84		
32	40.9	10 48			> 16.5	14.98	11.83	10.82	10.31		
33	41.0	11 01			> 16.5	12.22	10.11	9.00	8.11	7.48	
34	41.9	11 00			> 16.5		11.75	10.03	8.89		
35	42.1	11 43			> 16.5	12.46	10.25	9.43	8.71		
36	42.1	10 37		> 18.2	16.0	11.76	10.06	9.46	9.08		
37	42.9	11 42			> 16.5	13.63	11.33	10.15	8.94		

Notes to Table 2: The nine IR sources marked in the last column also show up on the R and I plates of CEN.

viously at $JHKL$ (Chini 1982, CK1). Apart from CEN 14, 26, 27, 37 and 40 which seem to be variable stars, the new results agree fairly well with our former photometry; a few measurements where the deviations are slightly larger than 0.2 mag are probably due to different apertures and/or chopper throws in combination with the crowded field and large variations of the extended background emission. To give a complete view of the SEDs and to facilitate the access to the optical measurements we have included in both tables the $UBVRI$ data by CEN.

3. Two-colour-diagrams

Two-colour-diagrams (TCDs) are a potential tool to investigate photometric data in terms of reddening and excess emission. The classical UBV diagram even allows simultaneously the determination of spectral type and reddening for stars earlier than B3 with spectroscopic accuracy. TCDs including only wavelengths $\geq 0.44\,\mu$m cannot clearly distinguish between intrinsic stellar colours and extinction. Vice versa, the coincidence of the stellar sequence and the reddening path allows to detect deviations from the expected loci and to examine the law of interstellar extinction in TCDs containing B and V (CK1).

TCDs constructed exclusively from NIR colours have been studied by Chini et al. (1992). The comparison of the loci of reddened stars, warm dust of 750 to 2000 K and black bodies of 1000 to 30000 K showed that the most commonly used JHK diagram has several disadvantages: i) The H-band may be contaminated by emission associated with the formation of

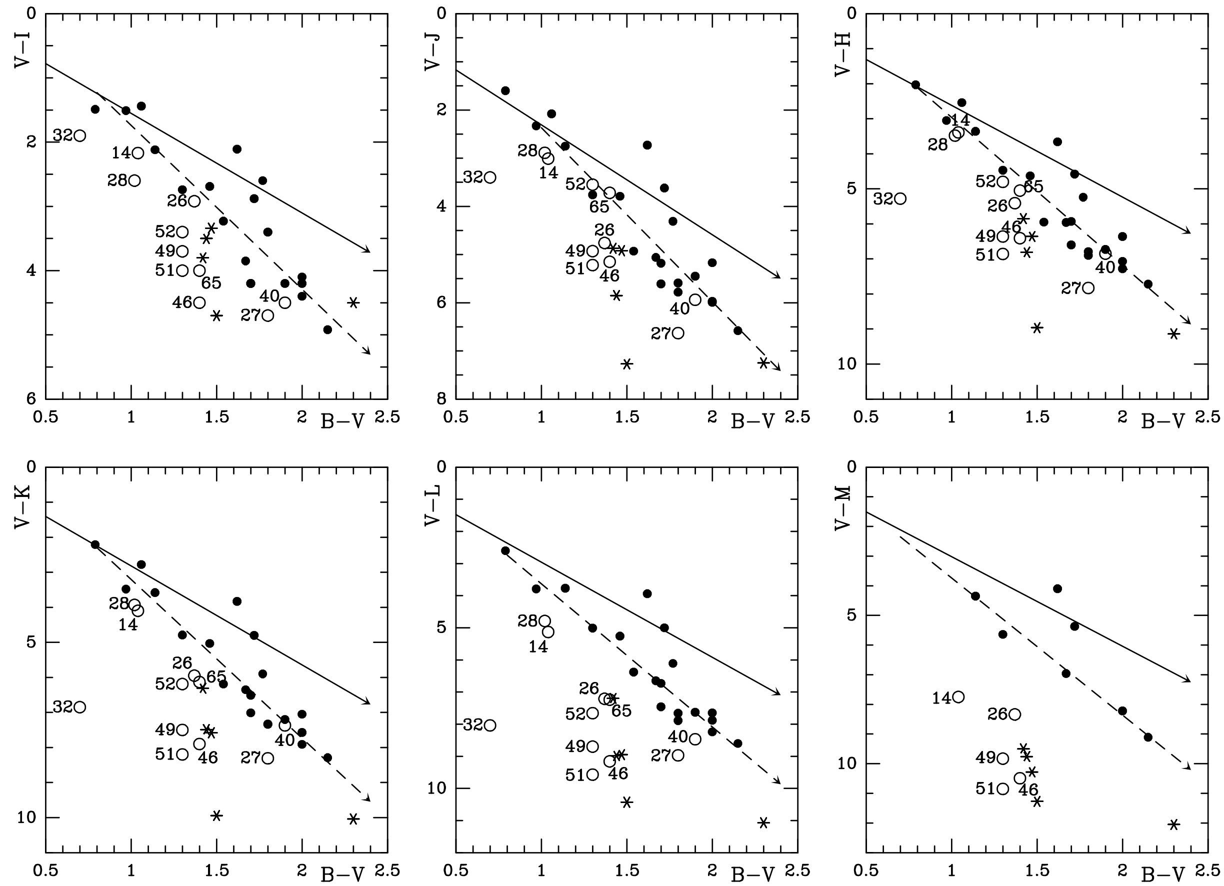

Fig. 1. Two-color-diagrams for the sample of 32 visible stars; normal stars without IR excess are marked as dots (•), excess objects are marked as circles (∘). The cocoon stars found by CK2 are included for comparison and are shown as stars (∗). The solid lines denote the normal law of interstellar extinction, the dashed lines indicate the special reddening vectors within M 17.

molecular hydrogen and the absorption by H^- in cool stellar atmospheres. ii) Emission lines as seen e.g. in TTauri stars contribute significantly at 1.6 μm. iii) The reddening path and the locus of dust emission are very similar, making a discrimination between the two effects rather difficult. As shown by Aspin & Barsony (1994) from observational data in the literature, the locus of many TTauri stars and protostellar objects fall into the region of normal JHK colours. On the other hand, JKL and JKM TCDs provide a situation where the loci of main sequence stars earlier than F0 and the reddening vector are identical, thus allowing to predict the locus of reddened stars very accurately while simultaneously the locus of dust emission separates very clearly. Therefore, such diagrams are ideal for detecting anomalies in the SEDs, i.e. IR excesses due to circumstellar emission.

In order to investigate the extinction law in M 17 and to identify sources with IR excess we have plotted the photometric data in form of several TCDs. Fig. 1 shows six TCDs for 32 "*visible*" stars with $UBVRI$ data from CEN and NIR data from the present work (c.f. Table 1). Only CEN 44 has been omitted from the diagrams because the $UBVRI$ data which were taken in 1977 and the new NIR data do not fit smoothly together, indicating variability of the star between the two epochs. Furthermore we have constructed three NIR TCDs (Fig. 2) which contain both the 32 "*visible*" stars and the 37 "*IR sources*" from Table 2. As explained below in more detail, the symbols in both Figures correspond to the following classification: (•) 20 "*visible*" stars without any indication for an IR excess throughout all TCDs (including the two foreground giants CEN 0 and 10), (∘) 11 "*visible*" stars with IR excesses in Figs. 1 and 2, (▪) 28 pure "*IR sources*" without peculiar colours, (□) 9 sources with IR excess from the sample of "*IR sources*". For comparison, the "*cocoon stars*" (∗) found by CK2 are included in all TCDs.

4. The reddening law

Cardelli et al. (1989) have shown that the law of interstellar extinction can be described by a single parameter, i.e. the ratio of total to selective extinction $R = A_V/E_{B-V}$. In fact, the shape of the extinction curve in the IR seems to be rather uniform and independent of R (Jones & Hyland 1980, Clayton & Mathis 1988, Tapia et al. 1988, Whittet 1989). As a consequence, deviations from the normal reddening law are not detectable in TCDs constructed from NIR colours alone, but require measurements at B and V. TCDs of the form $(V-\lambda)$ vs. $(B-V)$, where λ denotes any waveband longward of V are very sensitive to detect anomalous extinction without knowing exact stellar spectral

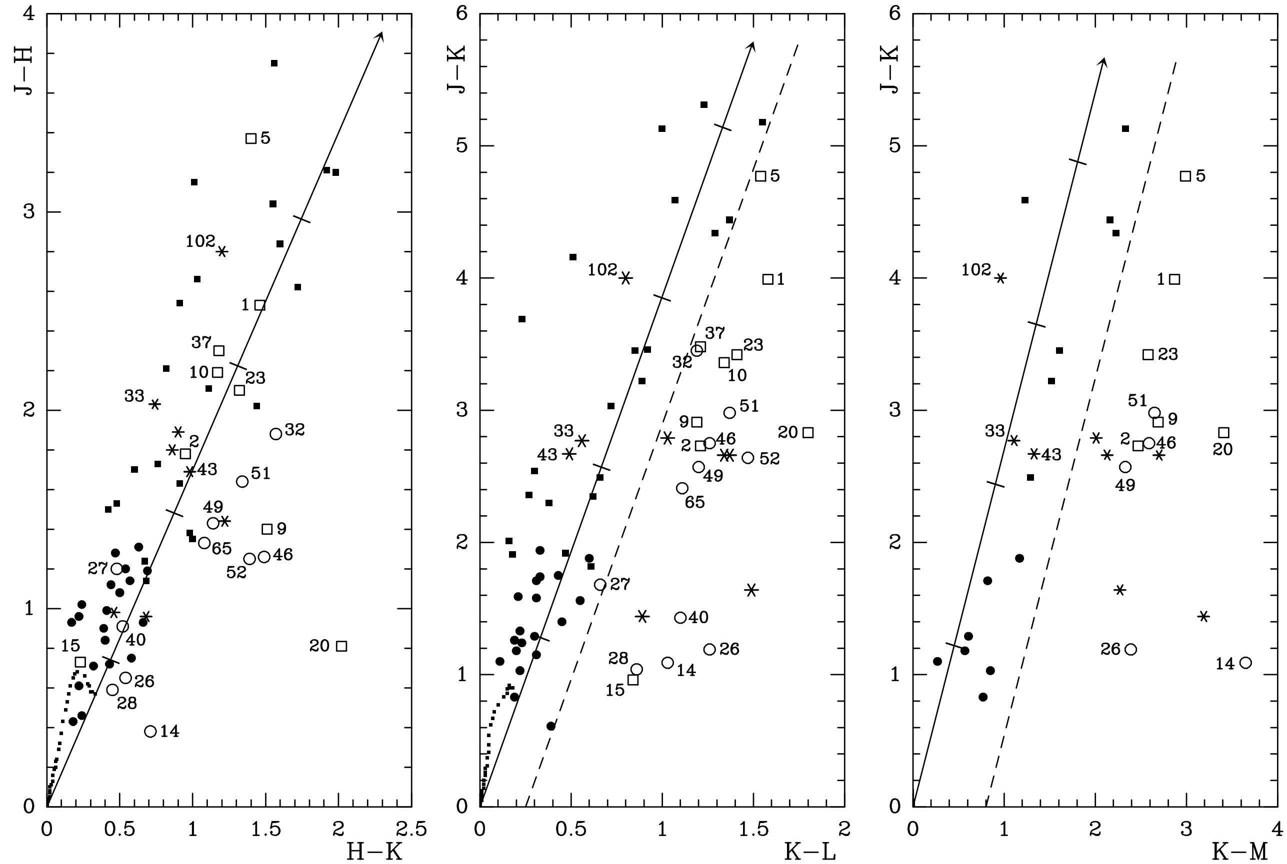

Fig. 2. Two-colour diagrams for the sample of 32 visible and 37 IR stars; same notation as Fig. 1. The dotted curve represents the main sequence taken from Koornneef (1983b). IR sources without excess are shown as filled squares, those with excess as open squares. The solid lines denote the reddening path; tickmarks correspond to 10, 20, 30 and 40 mag of visual extinction (R = 4.8). The dashed lines indicate the relations $(K-L) = 0.26(J-K) + 0.25$ and $(K-M) = 0.37(J-K) + 0.80$, respectively, which separate normal stars from IR excess objects.

types (CK1). It must only be verified that the stars under consideration are earlier than about F0 V and free of circumstellar dust emission. In the case of M 17, the first criterion is securely fulfilled, taking into account the sensitivity of the survey by CEN: At a distance of about 2.2 kpc and a visual foreground extinction of $A_V \sim 3$ mag due to the diffuse interstellar medium between the sun and M 17, a limiting magnitude of V = 18.2 corresponds to M_V = 3.5 mag. This is equivalent to a F2 V star. Taking into account the local extinction within M 17 ($A_V > 3$ mag) the detection limit is shifted to considerably earlier spectral types.

To check the second criterion, i.e. the absence of excess emission due to circumstellar dust, we have examined all stars throughout the TCDs in Fig. 2. In total we find 18 early type stars free of IR excess which are confined to relatively narrow lines (dashed) in the TCDs of Fig. 1. These loci have the form $(V-\lambda) = E_\lambda \cdot (B-V) + C_\lambda$ where E_λ is the colour excess ratio at the waveband λ normalised to E_{B-V} = 1. With increasing $(B-V)$ the dashed lines deviate significantly from the normal reddening vectors indicated by the solid lines. The new values for the specific colour excess ratios $E_{V-\lambda}/E_{B-V}$ are summarised in Table 3 and describe the reddening law within M 17; although not explicitely shown in Fig. 1 we have also calculated the corresponding value for the R-band. The ratio of total to selective extinction is extrapolated to be 4.8 ± 0.2. These results agree with our former estimates (CEN, CK1) but this time are based on almost three times more stars and include the M-band. For comparison the extinction law for the diffuse interstellar medium (ISM) is given. Values at $BVRI$ are taken from Schultz & Wiemer (1975), those at $JHKLM$ are averages calculated from the results published by Koornneef (1983b) and Rieke & Lebofsky (1985); the N-value also stems from the latter authors. Theoretical dust models which fit the extinction law of M 17 have demonstrated that there exists no correlation between the ratio of total-to-selective extinction and the mean dust grain radius (CK1).

In all TCDs of Fig. 1 the lines of normal and anomalous reddening intersect at $(B-V) \sim 0.8$, corresponding to $E_{B-V} \sim 1$ for early type stars. In agreement with CEN and CK1 we interpret this result as to originate from a normal foreground extinction of about 3 mag towards M 17. We want to emphasis again that the high value of R = 4.8 does not affect the slope of NIR reddening vectors in Fig. 2: if we calculate the average locus of the 18 normal early type stars used for deriving the reddening vectors in Fig. 1 we obtain NIR colour excess ratios that are consistent

Table 3. Extinction law in M 17 and the diffuse ISM

λ	$E_{V-\lambda}/E_{B-V}$		A_λ/A_V	
	M 17	ISM	M 17	ISM
B	1.00	1.00	1.208	1.324
V	0.00	0.00	1.000	1.000
R	1.09 ± 0.13	0.78 ± 0.02	0.773	0.748
I	2.55 ± 0.26	1.60 ± 0.03	0.469	0.482
J	3.61 ± 0.25	2.25 ± 0.03	0.248	0.274
H	4.22 ± 0.29	2.59 ± 0.04	0.121	0.165
K	4.53 ± 0.27	2.78 ± 0.04	0.056	0.103
L	4.46 ± 0.28	2.94 ± 0.03	0.071	0.052
M	4.62 ± 0.15	3.02 ± 0.03	0.038	0.026
N		2.93		0.052

with the normal interstellar values and thus with the reddening vectors in Fig. 2. This is in agreement with the results from other regions (see the references at the beginning of this Section) and corroborates the interpretation by Cardelli et al. (1989) about the uniformity of the NIR extinction law.

5. The stellar content

Due to the remarks above it is obvious that the present NIR study cannot further contribute to the classification of stars in terms of spectral types and/or luminosity classes. For that purpose the classical methods like UBV photometry and MK spectroscopy and/or the K-band classification system developed by Hanson & Conti (1994) are required. For main sequence stars earlier than B3, UBV photometry is still a very efficient tool as shown by the fact that all O-type stars identified by CEN as such on the basis of their UBV colours have been verified recently as ionising sources of M 17 by Hanson & Conti (1995). The purpose of the following section is to investigate whether there are additional objects similar to the "*cocoon stars*" found by CK2, i.e. to identify new IR excess objects on the basis of their location in various TCDs.

5.1. Normal stars

As already discussed in the previous section and in agreement with CEN there are 18 normal early type stars among the 32 "*visible stars*" whose spectral types must be earlier than F2 V. CEN 0 and 10 were classified as foreground giants, CEN 44 was classified as B4 V but seems to be variable. Variability is a general problem when discussing TCDs and SEDs because data taken at different epochs may simulate unusual colours and/or excesses. Thus, for the sample of "*visible stars*" some caution is necessary when evaluating the TCDs in Fig. 1 that contain B and V data from 1980 and NIR data from 1992 to 1995. From the fact, however, that these 18 stars do not show any excess emission in the TCDs of Fig. 2, which are based on data from a single epoch only, one may conclude that they are indeed normal. In this context we want note that the NIR variability observed for some objects in M 17 is of the order of several tenths of a magnitude (CKC) whereas an IR excess produced by circumstellar dust typically exceeds several magnitudes.

From the apparent colours $K-L$ and $K-M$ one may estimate the visual extinction towards the normal visible stars; the influence of the unknown spectral types is negligible: At a distance of 2.2 kpc - equivalent to a distance modulus of 11.7 mag - and with a foreground extinction of $A_K \sim 0.3$ mag, the faintest sources that can be reached by our limit of K = 12.2 mag have $M_K \sim 0.2$ mag, corresponding to spectral type A0 V. The local extinction within M 17 shifts this limit even towards earlier spectral types. The intrinsic colours $(K-L)_0$ and $(K-M)_0$ for main sequence stars from O6 to G3 are generally close to zero ($< \pm 0.04$ mag) (Koornneef 1983b), i.e. they lie within our photometric accuracy. We thus may convert the apparent colours directly into a visual extinction, using the relations between A_V and the IR colours according to Table 3: $A_V = 19.4\,(K-L)$ and/or $A_V = 14.3\,(K-M)$. The observed colour range of $0.2 \leq (K-L) \leq 0.6$ translates into $4 \leq A_V \leq 12$ mag for a normal extinction law with R = 3.1. Using the appropriate R value of 4.8 as derived above A_V will increase by 50%. Similar results are obtained from the $K-M$ colours. These estimates agree with the A_V results derived by CEN from UBV photometry.

Among the 37 "*IR sources*" there seem to be further 28 normal stars as witnessed by their location close to or left of the reddening lines in Fig. 2. They partly overlap with the "*visible*" sample but several sources are significantly redder, extending until $K-L \sim 1.5$ and $K-M \sim 2.3$. For a normal main sequence star these colours translate into a visual extinction of about 33 mag (R = 3.1) or 50 mag (R = 4.8). If these sources were background giants, small corrections due to their intrinsic colours have to be applied, yielding a total extinction of ~ 45 mag throughout the molecular cloud of M 17. In summary, one may conclude that the present NIR survey does not extend the initial mass function towards spectral types later than B but reveals a number of additional early type stars that are embedded even more deeply than the previously known cluster members.

5.2. IR excess objects

According to their location in Fig. 1 there are nine "*visible stars*" with clear IR excess (CEN 14, 26, 27, 32, 46, 49, 51, 52, 65); their anomalous colours can also be traced throughout Fig. 2. In addition, CEN 28 and 40 seem to be slightly below the special reddening lines in Fig. 1, indicating a faint excess. When investigating their colours in the JKL plot of Fig. 2 this excess becomes quite pronounced. Thus, we regard 11 "*visible stars*" as objects with an IR excess; they are marked as circles in all TCDs. Among the pure "*IR sources*" there are another 9 stars (IRS 1, 2, 5, 9, 10, 15, 20, 23, 37) whose location in Fig. 2 argues in favour of an IR excess; these objects are marked as open squares.

In the crowded cluster field of M 17 it is very likely that faint red companions, contained in the aperture, may affect the photometry and thus simulate an IR excess. We therefore have inspected our CCD frames at JHK (CKC) in order to search for red companions close to the 20 new IR excess objects. Down to limit of $K \sim 16.5$ mag we only find one additional source within the aperture of our photoelectric photometry. This source is located 2″ SW of IRS 9 and is only marginally visible at K; it thus cannot contribute significantly to the JHK colours of IRS 9 which are normal in Fig. 2. A source within the OFF beam of the photoelectric observations will only decrease the IR flux and thus suppress an IR excess.

The fraction of IR excess objects among the "*visible*" sample is 34% - among the "*IR*" sample $\sim$ 24%; including the five cocoon stars, these numbers turn into 47% and 27%, respectively. All stars have in common that their SEDs strongly increase with increasing wavelength. Compared to the "*visible stars*", the average apparent K magnitude of the "*IR sample*" is 0.7 mag brighter whereas the average I brightness is more than 3 mag fainter. This demonstrates that the SEDs of the pure "*IR sources*" decrease faster towards shorter wavelengths reflecting their larger extinction. Four IR excess objects (CEN 14, 26, 27, 40) have been observed during different epochs. They all show variability of several tenths to about 1 magnitude at NIR wavelengths. As it will be discussed in our next paper (CKC) this seems to be a common property of the class of "*cocoon stars*" discovered by CK2.

6. Discussion

In the following we investigate the evolutionary stage of the IR excess objects in M 17 by comparing them with other young stellar objects (YSOs).

6.1. The spectral index $\alpha_{\rm IR}$

The spectral slope between 2.2 and 10 or 20 μm, defined as

$$\alpha_{\rm IR} = \frac{{\rm d}\log(\lambda \cdot F_\lambda)}{{\rm d}\log(\lambda)} \qquad (1)$$

is widely used to describe the evolution of YSOs. The observational evidence that $\alpha_{\rm IR}$ attains values between ± 3 for YSOs in the Ophiuchus dark cloud led to the following classification scheme (e.g. Lada 1987): Values of $\alpha_{IR} > 0$ are typical for the earliest stages of evolution where most of the observed luminosity is derived from accretion. The corresponding objects, referred to as Class I, are regarded as true protostars. Objects belonging to Class II ($-2.0 < \alpha_{\rm IR} < 0$) and Class III ($\alpha_{\rm IR} < -2.0$) are believed to be pre-main sequence stars surrounded by optically thick and optically thin circumstellar disks, respectively (André & Montmerle 1994). We note, that the steepest negative spectral index of -3.0 is always obtained when the observed wavebands fall into the Rayleigh-Jeans part of the blackbody emission.

In Fig. 3 we have calculated $\alpha_{\rm IR}$ between 2.2 and 20 μm (upper panel) for the emission of optically thin dust and a blackbody as a function of A_V. Values of $\alpha_{\rm IR}$ between 0 and +3 correspond either to dust radiation of 300 K $< T_{\rm d} <$ 600 K or to blackbody emission with slightly higher temperatures $T_{\rm bb}$. Obviously, the influence of extinction is not entirely negligible: $A_V > 40$ mag

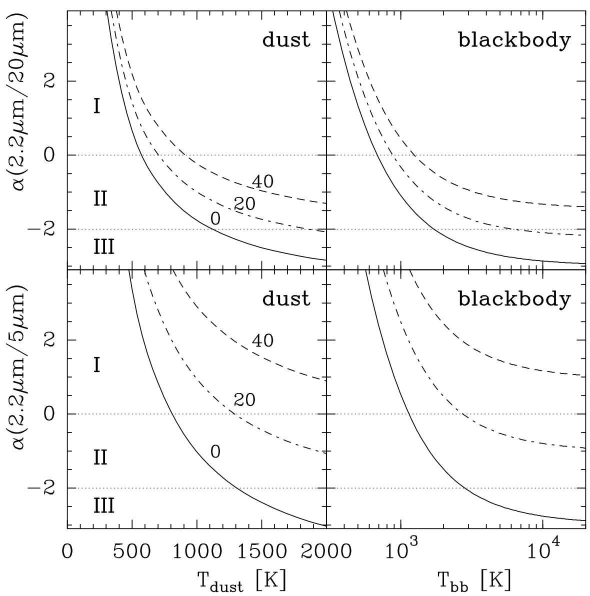

Fig. 3. Spectral indices $\alpha_{\rm IR}$ for the wavelengths interval 2.2 - 20 μm (upper panel) and 2.2 - 5 μm (lower panel) as a function of temperature and visual extinction A_V for the emission of interstellar dust and stellar radiation (solid: A_V = 0, dash-dotted: A_V = 20, dashed: A_V = 40 mag). The definition regions for Class I, II and III are separated by the horizontal dotted lines. The dominating influence of extinction with decreasing wavelength is demonstrated in the lower panel.

may shift Class II objects of 600 $< T_{\rm d} <$ 900 K into Class I. Moreover, all sources suffering $A_V > 80$ mag always appear as Class I objects; their detection at K, however, is rather unlikely. The influence of extinction becomes increasingly important when a spectral slope between 2.2 μm and wavelengths shorter than 10 μm is employed. The lower panel of Fig. 3 shows an example for $\alpha_{\rm IR}$ between 2.2 and 5 μm: Already a visual extinction of $A_V \geq 30$ mag converts any emission of arbitrary temperature into a Class I object, no matter whether the origin is pure stellar radiation or optically thin dust. Eventually, extinction becomes the dominating effect when deriving spectral indices e.g. from JHK data alone, thus making the classification of YSOs impossible.

6.2. The evolutionary stage of the IR excess objects

Figs. 1 and 2 also show the location of some of the "*cocoon stars*" classified as such by CK2. Five of them (CEN 24, 31, 35, 43, 47) have data at B and V; they all lie in the region of excess emission in Fig. 1. In Fig. 2 the situation is less clear: While in the $(J-H)/(H-K)$-diagram no cocoon star displays abnormal colours, most of them develop an IR-excess with increasing wavelength. CEN 43 does not show a clear excess at longer wavelengths. The IR spectroscopy by Hanson & Conti (1995) classifies CEN 43 as a normal O type star, which does not exclude the presence of a dusty cocoon. According to its spectral index $\alpha_{\rm IR}$, which is 0.3 and 0.1 for 10 and 20 μm, respectively, CEN 43 might still be a Class I object. Only CEN 33 and 102 remain left of or close to the reddening line in all NIR-diagrams; both stars are classified as late type objects by Hanson & Conti (1995). In summary, this leaves six true "*cocoon stars*" in M 17 (CEN 24, 31, 34, 35, 43, 47) five of which have photometric data until 20 μm. Their SEDs fulfill the original condition $\alpha_{IR} > 0$ and thus qualifies them as genuine Class I objects. The empirical classification scheme for Class I suggested by Lada (1987) was also based on observations of five sources located in the Ophiuchus cloud (Lada & Wilking 1984, Elias 1978). Comparing both groups of Class I objects in M 17 and in Ophiuchus we find several differences:

i) The SEDs between 2.2 and 10 μm in Ophiuchus are steeper than those in M 17. Furthermore, all objects in Ophiuchus with $\alpha_{\rm IR} > 0$ are "*invisible*" whereas those with $\alpha_{\rm IR} < 0$ are "*visible*" (Lada 1987). Such a clear division does not exist in M 17: five out of the six "*cocoon stars*" are "*visible*". These differences are probably all due to the amount of interstellar extinction: From the J and K fluxes Lada & Wilking (1984) estimated A_V values between 30 and 50 mag for the sources embedded in the Ophiuchus cloud. Employing the same technique and using the relation $A_V \sim 5.6(J-K)$ as derived from Table 3 we obtain only $6 < A_V < 27$ mag for the M 17 sources; both estimates assume that the intrinsic colours of the stars are negligible and that they have no significant excess emission in the $K-$band. This comparison shows that the $\alpha_{\rm IR}$ of the Ophiuchus sources is more contaminated by extinction than that of the M 17 sources. As shown by Chini & Krügel (1985) only little circumstellar dust ($A_V < 0.5$ mag) is necessary to produce large IR excesses at $\lambda > 4\,\mu$m. We therefore conclude that the steepness of the SEDs in Ophiuchus are to some extent the result of the large interstellar extinction whereas the SEDs in M 17 are intrinsically steeper, reflecting the dominant influence of circumstellar emission.

ii) Integrating the observed luminosity $L_{\rm obs}$ from 1.25 to 4.8 μm for both samples of YSOs we obtain an average value of $0.4 \pm 0.1\,{\rm L}_\odot$ in Ophiuchus, excluding the object EL 29 which has $5\,{\rm L}_\odot$. The corresponding value for the "*cocoon stars*" is $74 \pm 14\,{\rm L}_\odot$. The observed luminosity $L_{\rm obs}$ between 1.2 and 20 μm for the five Ophiuchus sources ranges between 0.8 and 14.8 ${\rm L}_\odot$ with an average of $4.9 \pm 2.6\,{\rm L}_\odot$ as derived from the data by Lada & Wilking (1984). The corresponding interval for the "*cocoon stars*" in M 17 is $122 \leq L_{\rm obs}[{\rm L}_\odot] \leq 535$ with a mean of $300 \pm 70\,{\rm L}_\odot$. These estimates suggest that the Class I sources in M 17 are a factor of 60 more luminous than those in Ophiuchus.

After these remarks one may investigate the evolutionary status of the 20 new IR excess objects in M 17 by using the "*cocoon stars*" as template objects. Comparing the NIR properties of both groups, all newly identified IR excess objects lie significantly below the reddening lines in Fig. 2 and are located in the same region as the six true "*cocoon stars*". Their location is characterized by $(K-L) > 0.26(J-K) + 0.25$ and $(K-M) > 0.37(J-K) + 0.80$. Because these relations are independent of the amount of extinction they directly measure the emission of circumstellar dust. As a consequence they are equivalent to the Class I criterion ($\alpha_{\rm IR} > 0$) and may be used as indicators for the evolutionary stage of an object in the absence of data longward of 4.8 μm.

The mean $L_{\rm obs}$ from 1.25 to 4.8 μm for the 20 IR excess sources in M 17 is 26 ± 4 and thus a factor of 60 higher than the corresponding value in the Ophiuchus cloud. This comparison shows again that the "*cocoon stars*" and the new IR excess objects belong to the same population of YSOs. They represent the youngest generation of early type stars in M 17 and are still enshrouded by the remnance of their protostellar cloud. The fact that these early stages of stellar evolution can be observed even at wavelengths below 2.2 μm is due to the fact that the ionizing radiation and the stellar winds from the nearby O type stars have partly cleared the region. We suggest, that these M 17 objects are the first high mass counterparts of classical Class I sources.

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