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Spectral types of a few 'unidentified' Equatorial Infrared Catalogue 1 (EIC-1) sources

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Abstract. Spectral types are assigned to 13 'unidentified' Equatorial Infrared Catalogue 1 (EIC–1) sources from a study of their spectra in the wavelength interval 5200–8700 Å. Their spectral types range from M4.5 to M6.5. We infer from a combination of the data on their $[J-K]$ colours and optical spectra that these sources are stars of luminosity class III. EIC 258 has a $[J-K]$ colour which is higher than the characteristic value for its spectral type by 0.2. The star is also found to be a variable.

Key words : EIC–1 sources, 'unidentified'—spectral types—infrared colours—M-type stars

1. Introduction

The Equatorial Infrared Catalogue 1 (EIC–1) of Sweeney *et al.* (1978) lists 896 sources detected with high confidence at 2.7μm using detectors based on an U.S. air force satellite. These sources have flux densities greater than 4×10^{-16} W cm^{-2} μm^{-1} and lie in the declination zone $|\delta| \leqslant 10°$. Their flux densities are reported to have an r.m.s. error of 14% and the positional coordinates an r.m.s. error of 2 arcsec. 808 of the sources in EIC–1 have been identified with sources in the (i) SAO catalogue, (ii) the AGK 3, (iii) the Two-micron sky survey (TMSS) catalogue of Neugebauer & Leighton (1969), and (iv) the Air Force Geophysical Laboratory (AFGL) infrared sky survey catalogue of Price & Walker (1976). Among the identified soures 328 are classified as K-type and 274 as M-type stars, and are likely to be giants.

A total of 88 sources failed to satisfy the criteria set by Sweeney *et al.* (1978) for identification and we refer to them as 'unidentified' sources. Heinsheimer *et al.* (1978) identified 11 of these 'unidentified' sources with variable stars and another two with suspected variable stars. Verma & Iyengar (1983) identified 22 of the remaining 75 'unidentified' sources with stars in the BD catalogue; two of them are also HD/HDE sources. Ghosh *et al.* (1984) identified 85 of the initially 'unidentified'

88 EIC–1 sources with optical objects on the Palomar observatory sky survey (POSS) prints; they also determined the *JHK* magnitudes of these sources. They noted that the frequency distribution (in terms of their 2.7 μm flux density) of the 'unidentified' EIC–1 sources was similar to that of the identified EIC–1 sources with a large overlap in their distributions and that the lack of identification of the 'unidentified' sources was possibly due to their being unusually faint in the visible band. They expected them to have interesting spectra.

We therefore undertook an optical spectroscopic study of a few of the brighter 'unidentified' sources (as judged from the *P* and *R* magnitudes tabulated by Ghosh *et al.* 1984) to search for interesting features (if any) in their spectra and to determine their spectral types.

2. Observations

Spectrograms of 12 sources were obtained with an image-tube spectrograph at the Cassegrain focus of the 102-cm reflector at Kavalur observatory. Ten of these were observed at a reciprocal dispersion of 125 Å mm^{-1} in the wavelength range 5200–8700 Å using a 300 lines mm^{-1} grating blazed at 7615 Å, and a camera of 250 mm focal length. Kodak 098–02 plates were used in contact with the fibre-optic output plate of the Varo single-stage image intensifier. Several standard stars from the list of Morgan & Keenan (1973) were also observed. The spectrograms of program stars were widened to 200–300 μm and those of standard stars to 400–500 μm. The remaining two sources were observed at a lower dispersion of 256 Å mm^{-1} using a 125 mm camera, one with and the other without the image tube. These spectra were not widened.

Some of these sources were observed earlier also with an objective-grating set up, utilizing a 150 lines mm^{-1} transmission grating and the 250 mm camera. These observations were later terminated in favour of slit spectroscopy. Though most of the sources were reobserved, it was not possible to obtain a slit spectrum of EIC 258, since the star was discovered to be a variable, and was too faint at the time of observations with the Cassegrain spectrograph. The spectral type estimated here is based on unwidened objective-grating spectrogram and is relatively less accurate.

3. Spectral classification

All the observed sources exhibited M-type spectra characterized by numerous molecular absorption bands. The spectral types were assigned by comparing with the spectra of standard stars obtained by us, and also with the ones published by Sharpless (1956), and Keenan & McNeil (1976). The criteria of Sharpless in the region 7600–8600 Å were found particularly useful since his resolution is comparable to ours These were supplemented by the criteria of Keenan & McNeil in the visual region for stars of spectral type M4 – M5. We summarize below spectral characteristics of different types in the range of types M4 – M7, which encompasses the spectral types of all observed sources.

M4 : TiO bands at 5448, 5597, 5849, 6158, 6651, 7054, 7589 and 8430 Å are clearly visible. Ca II 8498, 8543 and 8662 Å are distinctly seen. VO 7865, 7896, 7939 Å are too weak.

M5 : TiO bands increase in strength, Ca II triplet is weaker, and VO bands become stronger.

M6 : TiO bands increase in strength, Ca II is very weak and VO bands continue to be weak.

M7 : TiO bands are still stronger, Ca II is invisible and VO bands are fairly strong.

Luminosity effects are less apparent in the stars of type M4 or later, both due to a smaller intrinsic spread in their luminosity and obliteration by TiO absorption (Sharpless 1956). Yet, the absence of CaH 6385 Å suggests that none of the observed sources is a dwarf and the absence of CN bands in the region 7800–8000 Å suggests that the stars are not supergiants. We thus place all the sources among the giants.

Our estimates of spectral types of these 13 sources are listed in table 1. Microphotometric tracings of a few representative spectra are shown in figure 1. All the 13 stars lie within a narrow range of spectral types between M4.5 and M6.5 and appear to be giants on the basis of optical spectra. This classification is consistent with the infrared colours (save EIC 258) as discussed in the following section.

Table 1. Spectral types of 13 EIC-1 'unidentified' sources

EIC No.	Spectral type	Date of obs. (U.T.)	$[J-K]^{(1)}$	Notes
61	M6 :	1983 Nov. 28.69	1.38	2,3,4
205	M5	1984 Mar. 19.68	1.28	
243	M4.5	1984 Mar. 19.73	1.24	
258	M6 :	1983 Apr. 30.64	1.52	2,5,6
260	M6.5	1984 Mar. 20.74	1.24	
322	M6	1984 Mar. 19.84	1.28	
327	M6.5	1984 Mar. 20.80	1.34	
371	M6	1984 Mar. 20.85	1.19	
392	M6.5	1984 Mar. 19.92	1.17	
411	M5	1984 Mar. 20.89	1.17	
439	M6:	1983 Mar. 1.90	1.32	2,3,6
482	M4.5	1984 Mar. 20.84	1.24	
492	M4.5	1984 Mar. 19.97	1.19	

1. Data from Ghosh *et al.* (1984)
2. Dispersion: 256 Å mm^{-1}.
3. Not widened.
4. Wavelength range 5700–7700 Å.
5 Objective grating spectrum.
6. Wavelength range 5200–6200 Å (without image tube)

4. Discussion

The optical spectra of the 13 observed sources appear normal and fall within a narrow range of spectral types between M4.5 and M6.5. All these sources appear to be giants. We plot in figure 2 their $[J-K]$ colours reported by Ghosh *et al.* (1984) against the spectral types as estimated here. The J and K magnitudes refer to the standard Johnson system. We also plot for comparison the mean $[J-K]$ colours for different spectral types, as determined by Lee (1970), Frogel *et al.* (1978) and Kodaira *et al.* (1979). The dwarf, giant and supergiant M-type stars are represented by different symbols in the figure. The giants and supergiants conform to a sequence distinctly different from the sequence of dwarfs. It is evident from the figure that all but EIC 258 conform well with the mean colours of high-luminosity M-type stars.

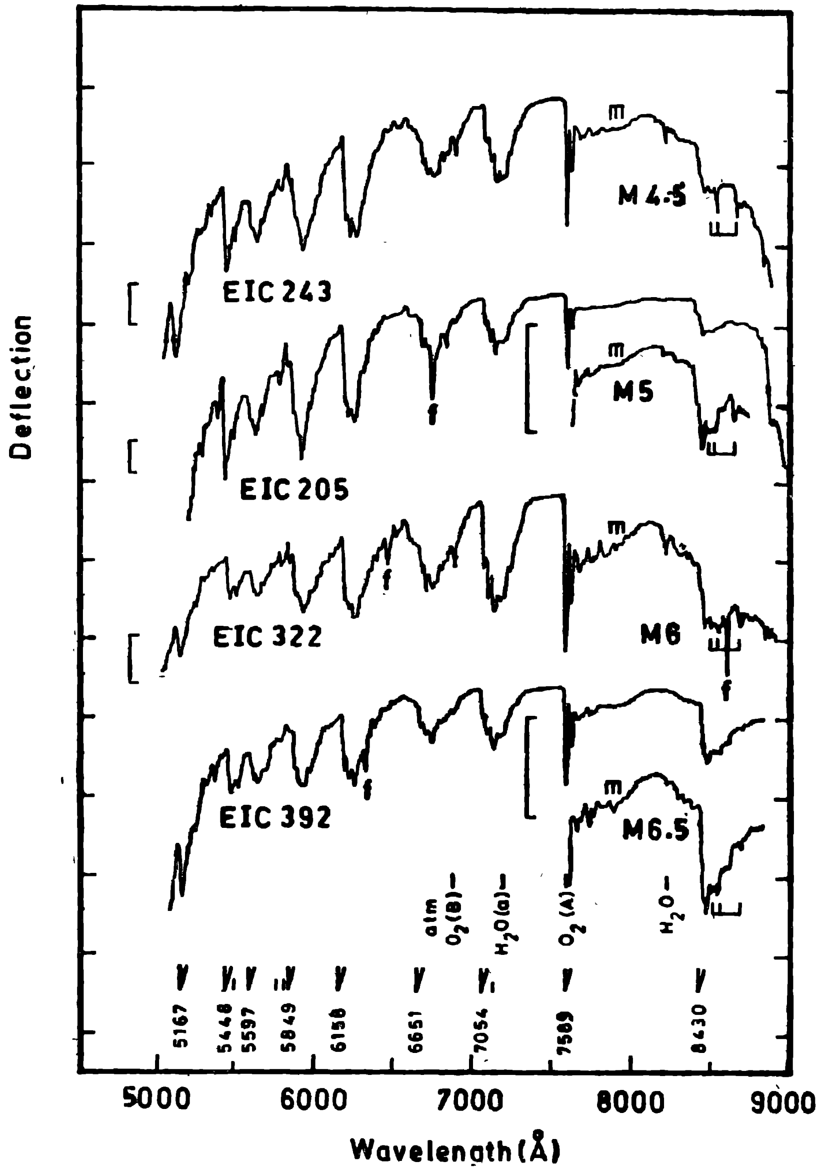

Figure 1. Microdensitometric tracings of a few representative spectra of the 'unidentified' EIC-1 sources. The deflections are on an arbitrary scale. Strong TiO bands are marked as 'V' at the bottom of the figure. The weaker bands, indicated by shorter marks, are at 5497, 5759, 5810 and 7125 Å. The atmospheric A and B bands due to O_2 (7594 and 6867 Å, and the 'a' and infrared bands of H_2O (7168 and 8228 Å) are also marked. The VO bands at 7865, 7895 and 7939 Å are marked above each spectrum, whereas the Ca II triplet (8498, 8543 and 8662 Å) is marked below. The image-tube flaws are marked 'f'.

The finding chart (magnified reproduction of POSS red print) for EIC 258 is presented in figure 3. It is seen that another stellar object of nearly similar brightness is at an angular distance of 22 arcsec from EIC 258. The [$P - R$] colours of the former and EIC 258 are 3.1 and 3.7 respectively (Iyengar 1984, unpublished). A slit spectrum obtained on 1984 April 19 and also the objective grating spectrum show that the companion is of type M4. EIC 258 is thus the redder of the two. Ghosh *et al.* (1984) used a field of view of diameter ~ 30 arcsec for carrying out photometric measurements. They centred the source in the field by maximizing

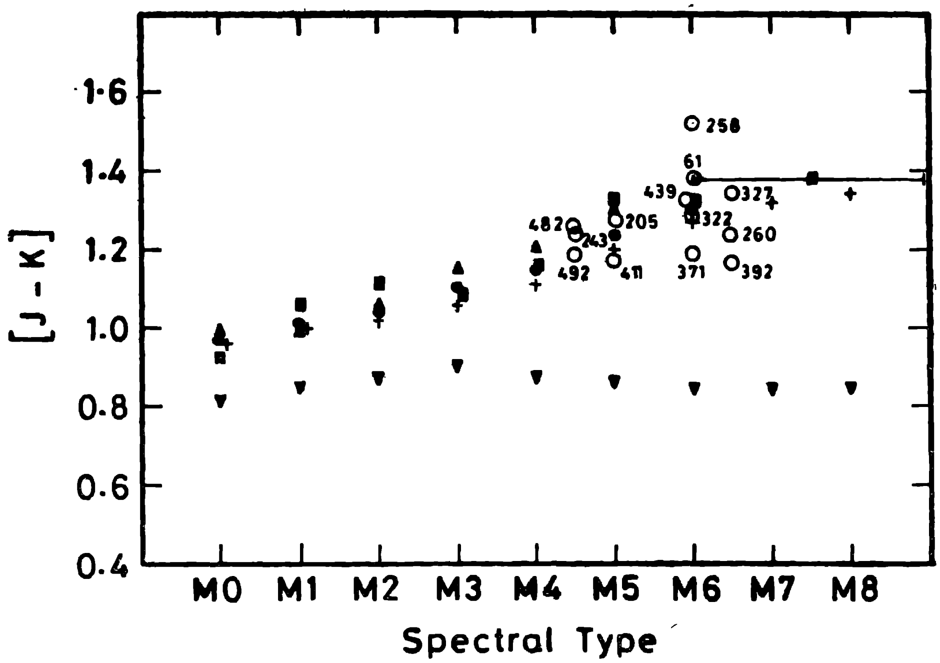

Figure 2. $[J-K]$ colour versus spectral type. The symbols ●, ■, + refer to data points for giants from Lee (1970), Kodaira *et al.* (1979), and Frogel *et al.* (1978), respectively. The symbols ▲, ▼ refer to data points for supergiants from Lee (1970) and dwarfs from Frogel *et al.* (1978), respectively. The points O refer to EIC sources with their numbers indicated.

the signal and carried out their measurements under conditions of stable guidance. The errors on their *JHK* magnitudes are $\lesssim 0.1$. The infrared signals detected by them appear therefore to be solely due to EIC 258.

EIC 258 and its optical companion have $V(= 0.37P + 0.63R)$ magnitudes of 10.0 and 9.0 respectively, on the POSS prints (as determined by K.V.K.I.). On the other hand, we estimate the visual magnitude of EIC 258 to be ~ 13 on 1983 April 30, judging from the objective grating spectra. The magnitude was estimated visually using the 102 cm reflector on 1984 June 29 to be ~ 15. The star is found to be variable at 2.7 μm according to the log of EIC-1 (Ghosh *et al.* 1984). EIC 258 thus appears to be a long-period variable.

The $[J-K]$ colour of EIC 258 is over 0.2 mag ($\gtrsim 2\sigma$) higher than the mean colour for its spectral type. Though our spectral type for this star is somewhat inaccurate (1 subclass), the discrepancy in colour is too high to be attributed to this error. Furthermore, the observed colour is redder than the mean colours of even late M-type giants and supergiants. Also, if at all there is a contamination from the optical companion, the observed $[J-K]$ colours would only become bluer than the actual colour. Thus the colour excess is real. The interstellar reddening does not make a significant contribution to $[J-K]$ excess (0.05 mag) since the star is at a relatively high galactic latitude ($+ 40^\circ.6$). Thus it is possible that EIC 258 has a cool circumstellar dust envelope. Further observations of this source at higher wavelengths (> 2.2 μm) are necessary to verify this conjecture. The star should also be monitored photometrically to determine the nature and period of light variations.

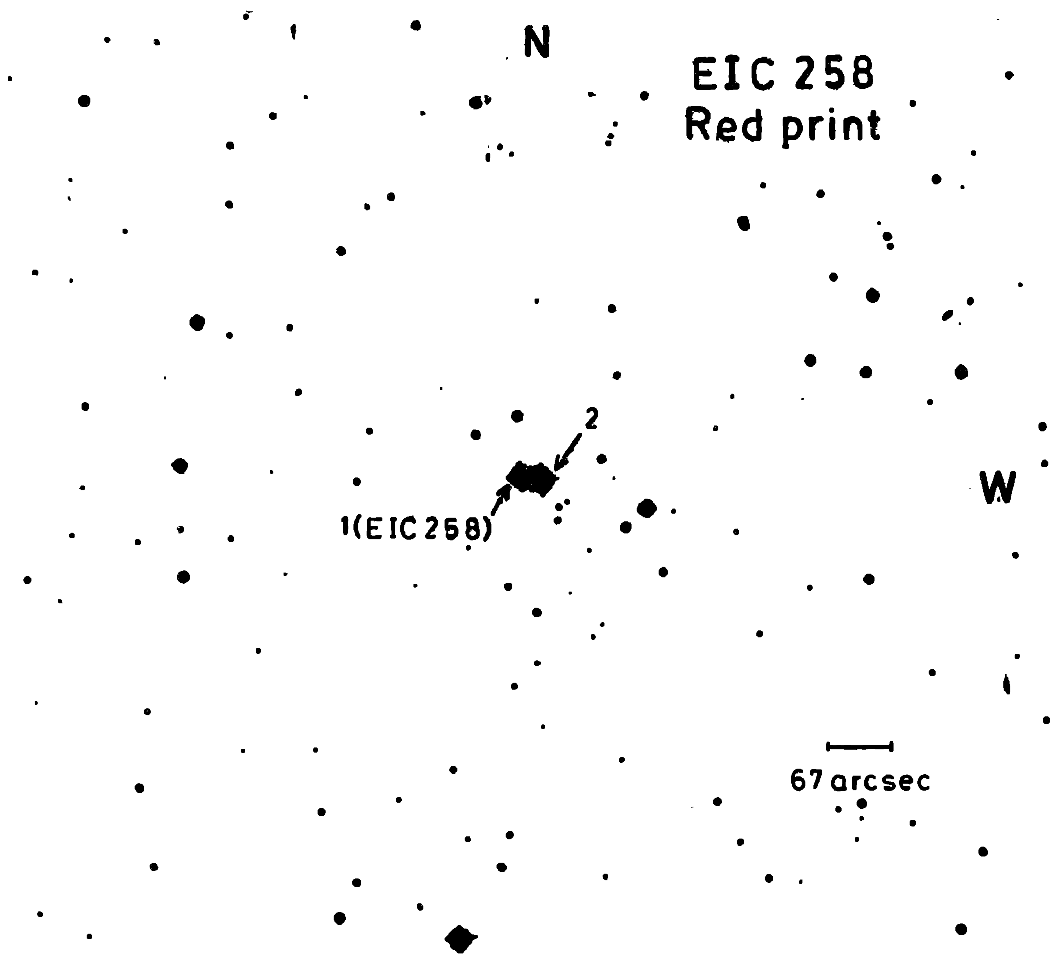

Figure 3. Finding chart for EIC 258. Source 1 is EIC 258. Sources 1 and 2 have angular separation of 22 arcsec. North is at the top and east is to the left of the figure.

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