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Equivalent widths of Ca II triplet lines of a few 'unidentified' IRAS sources

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Abstract. We report optical infrared spectroscopy of sixteen bright IRAS 'unidentified' sources with circumstellar envelopes in the region of the Ca II triplet lines. Several of these sources show low equivalent widths for the Ca II triplet lines. The implications of these for the spectral classification of these sources are discussed. IRAS 04101+3103 appears to be a Herbig Ae/Be star of spectral type Ale. The variations in the equivalent width of the Ca II triplet lines of IRAS 04184+2008 show it to be chromospherically very active. It is found to be a variable of Mira type with a period of ~322 days designated as DHK 42.

Key words : AGB, post-AGB, circumstellar matter, optical infrared spectroscopy, equivalent widths, Ca II triplet lines

1. Introduction

Iyengar and Parthasarathy (1997) carried out optical identification and BVRI CCD photometry of 33 'unidentified' IRAS (Infrared Astronomical Satellite) sources of a late type stellar nature. These had at that time no counterparts in other Astronomical Catalogues. These sources being late-type stars with circumstellar envelopes of gas and dust, are generally faint in the optical wavelength region. They are however, expected to be brighter in the R and I bands compared to those in B and V bands. We therefore carried out low resolution spectroscopic observations of some of the brighter ones from among these 33 sources in the optical-infrared region ($\lambda\lambda$8000-9000Å), using the Boller and Chivens spectrograph with the 2.3 m telescope at the Vainu Bappu Observatory (VBO) of the Indian Institute of Astrophysics at Kavalur, India. The most conspicuous feature of this part of the spectrum is the Ca II triplet λ8498, λ8542 and λ8662 lines which are formed due to transitions between the upper 4p $^2P_{1/2,3/2}$ levels and the lower metastable 3d $^2D_{3/2,5/2}$ levels. The Ca II triplet lines are not seriously contaminated by the atmospheric absorption lines, are comparatively free from blends, and are fairly strong even in

fainter stars. Mallik (1994) has discussed extensively the dependence of the equivalent width of Ca II triplet lines on stellar parameters such as log g, temperature and metallicity. It appears that the equivalent width (EQW) of the Ca II lines (sum of the equivalent width of the two lines λ8542 and λ8662) decreases rapidly with increasing log g for giants and supergiants, whereas the relation is flatter for dwarfs. The observations of Diaz *et al.* (1989, hereafter DTT) and the theoretical work of Erdelyi-Mendes and Barbuy (1991) show that the relative dependence of EQW on log g is strongest for high metallicity systems. The theoretical analysis has shown that the strong underlying relationship between the Ca II EQW and log g is modified by the calcium abundance and perhaps T_{eff}, and that giants and dwarfs respond differently to changes in metallicity. The observational data of DTT, Jones *et al.* (1984), and Zhou (1991) suggest that on an average the Equivalent Width (EQW) ratio of λ8542 / λ8498 lies between 2.1-2.5 and that of λ8542 / λ8662 between 1.2-1.4 (Mallik, 1994). Also the total equivalent width (i.e. the sum of equivalent widths) of the Ca II triplet lines progressively increases (on an average) as we go to stars of later spectral types and advance from main sequence to giants and then to supergiants, (not withstanding the effects of metallicity). One infers from the data presented by Mallik (1994) that the total equivalent width of the Ca II triplet lines ranges from about 6 to 9Å for stars of spectral type and luminosity classes from GIII to MI.

2. Equivalent widths of Ca II triplet lines

We used the Boller-Chivens spectrograph mounted at the Cassegrain focus of the 2.3 m telescope of VBO, Kavalur for determining the equivalent widths of the Ca II triplet lines. The original Boller-Chivens spectrograph has been modified to take in larger size gratings and to enable the use of GEC P8603 CCD chip obtained from Astromed Inc., U.K. of 385 x 578 pixels^2 (mounted in a liquid nitrogen dewar) as the detector. The observations were acquired using an 830 lines mm^{-1} grating blazed at 8200 Å as the dispersing element. It was oriented at an angle of 23.5 deg to cover $\lambda\lambda$8000-9000 Å range. This configuration yielded a dispersion of 75 Å mm^{-1}. The slit width of 0.35 mm used for the observations gave a spectral resolution of 2.6 Å (1.5 pixels). This resolution was sufficient to resolve fairly well the Ca II triplet lines and to enable measurement of the equivalent widths of stellar sources up to 12 magnitudes in V within reasonable exposure times of about 30 minutes. An Fe-Ne discharge lamp was used for line identification and wavelength calibration and the illuminated dome was used as the flat field source. A good number of bias, comparison and flat field frames were taken out at regular intervals of time during each night.

Data reduction was carried out with the 'RESPECT' software package (Prabhu and Anupama, 1991) installed at the VAX 11/780 system at VBO. This software package is based on the optimal extraction algorithm developed by Horne (1986, 1988) to extract the one-dimensional spectra from the two-dimensional CCD image. The reduction procedure included bias subtraction, flat-field correction, wavelength calibration and continuum fitting. The bias and the thermal background were subtracted from the raw spectrum. The spectrum was then divided by the flat field image to correct for pixel to pixel sensitivity differences of the detector. The observations upto September 1994 were reduced using the 'RESPECT' package but those obtained after that period were reduced using the various tasks provided under 'msspec'

routine in 'IRAF' package. Since the present study involved only measurements of the equivalent widths of the Ca II triplet lines, flux calibrations were not performed.

The significance of the location of the continuum for determining the equivalent widths of the Ca II triplet lines has been discussed by Mallik (1994). As pointed out by her, the location of the continuum is a very crucial factor in the determination of the strengths of the Ca II triplet lines. The practice in several previous studies using high resolution is to define the continuum by a straight line fit relative to the flux maxima near two chosen wavelength bands. Choosing a continuum between local maxima close to the Ca II triplet line under consideration has the effect of eliminating the contribution from the wings of the Ca II line which results in underestimating the equivalent width whereas choosing a straightline continuum between local maxima far to the right and left side of the Ca II line results in an overestimate of the equivalent width because of the inclusion of the TiO bands which appear in the vicinity of the Ca II feature extending from 8342 Å to 8620 Å. We however, fitted a single continuum from $\lambda\lambda$8450 to 8800 Å in the case of early type stars and from $\lambda\lambda$8450 Å to 8700 Å in the case of late type stars using a cubic spline function. The equivalent widths of all the observations were determined using the task 'splot' under 'specred' routine in 'IRAF' package.

Table 1. IRAS PSC data on the programme sources

No.	IRAS Name	$F_\nu(\lambda)$ in Jy				Var	LRS	GSC	
		12 μm	25 μm	60 μm	100 μm			J	V
1	00408 + 5933	11.78	10.89	7.39	8.27	0	1		9.81[c]
2	04101 + 3103	2.98	6.80	5.27	3.44	2	—		10.14[c]
3	04184 + 2008	16.00	5.22	0.95	—	9	—		14.38[b,c]
4	04386 + 5722	17.97	22.99	4.39	—	0	—		12.25[c]
5	05089 + 0459	7.37	21.89	11.10	3.78	1	—		14.08[b,c]
6	05113 + 1347	3.78	15.30	5.53	—	1	—		12.13[f]
7	05245 + 0022	1.31	3.28	2.48	1.62	1	—	10.29[d]	10.06[c]
8	12387 – 3717	96.49	61.36	7.67	2.63	0	—	12.10[b,d]	
9	14512 – 4746	14.28	4.25	0.62[a]:	—	1	16	9.69[d]	8.62[c]
10	15269 – 4400	67.99	47.88	4.37	—	1	28	12.26[d]	
11	17173 – 4632	10.58	3.39	1.21[a]:	—	3	—		11.87[e]
12	17174 – 4641	82.38	59.17	8.98	—	1	28		10.86[e]
13	17201 – 4613	68.10	29.83	5.39	—	5	15		9.05[e]
14	17318 – 3606	53.08	23.04	3.62	—	5	15		10.39[e]
15	18123 + 0511	10.72	11.02	4.21	—	0	14		10.10[b,c]
16	18599 + 2246	12.99	3.73	0.75	—	0	17		8.49[c]

[a] The symbol : by the side of the flux densities indicates their IRAS Quality Factor to be 2.

[b] The values listed refer to the mean values of magnitudes when measurements are available from more than one Sky Survey Plate in the same band.

Sky Plates from which GSC magnitudes have been obtained :

[c] Palomar VI [e] SERC V

[d] SERC J [f] Palomar V4

Table 2. Equivalent widths of Ca II triplet lines of the programme sources.

No.	IRAS Name	Date of Obsn. DD MM YY	Equivalent width Å λ 8498	λ 8542	λ 8662
1	00408 + 5933	01/01/94	1.97 ± 0.20	2.57 ± 0.31	2.66 ± 0.30
	,,	16/09/94	2.00 ± 0.06	4.26 ± 0.50	3.18 ± 0.43
	,,	17/09/94	1.95 ± 0.20	3.61 ± 0.13	2.86 ± 0.16
	,,		**1.97 ± 0.03**	**3.48 ± 0.85**	**2.90 ± 0.26**
2	04101 + 3103	15/09/94	–0.9 ± 0.3	0.2 ± 0.3	0.6 ± 0.5
3	04184 + 2008	05/01/93	0.32 ± 0.02	–0.23 ± 0.04	
	,,	06/01/93	0.38 ± 0.02	–0.28 ± 0.04	
	,,	01/01/94	0.50 ± 0.02	0.42 ± 0.04	
	,,	18/09/94	0.51 ± 0.02	1.07 ± 0.06	
	,,	17/12/94	0.25 ± 0.02	0.83 ± 0.03	
	,,		**0.39 ± 0.11**	**0.36 ± 0.61**	
4	04386 + 5722	02/09/94	1.55 ± 0.05	3.08 ± 0.15	2.80 ± 0.20
	,,	17/12/94	1.94 ± 0.06	3.27 ± 0.27	2.33 ± 0.14
	,,		**1.75 ± 0.28**	**3.18 ± 0.13**	**2.57 ± 0.33**
5	05089 + 0459	15/09/94	2.30 ± 0.17	2.65 ± 0.10	
6	05113 + 1347	14/03/95	1.62 ± 0.14	3.56 ± 0.09	2.54 ± 0.29
7	05245 + 0022	18/09/94	–0.7 ± 0.3	–0.1 ± 0.3	–0.6 ± 0.6
8	12387 – 3717	06/01/93	0.60 ± 0.05	0.75 ± 0.07	0.72 ± 0.11
9	14512 – 4746	13/03/95	1.24 ± 0.05	3.17 ± 0.47	2.24 ± 0.18
	,,	14/03/95	1.50 ± 0.22	2.87 ± 0.81	1.97 ± 0.68
	,,		**1.37 ± 0.18**	**3.02 ± 0.20**	**2.11 ± 0.19**
10	15269 – 4400	17/09/94	0.84 ± 0.03	1.30 ± 0.14	1.32 ± 0.14
	,,	18/09/94	0.75 ± 0.03	1.34 ± 0.19	1.12 ± 0.08
	,,		**0.80 ± 0.06**	**1.32 ± 0.13**	**1.22 ± 0.14**
11	17173 – 4632	17/09/94	0.76 ± .0.05	1.15 ± 0.10	1.36 ± 0.20
12	17174 – 4641	16/09/94	0.62 ± 0.05	1.64 ± 0.10	1.08 ± 0.10
13	17201 – 4613	17/09/94	0.78 ± 0.05	1.41 ± 0.10	1.68 ± 0.10
14	17318 – 3606	15/09/94	0.46 ± 0.05	0.92 ± 0.25	0.46 ± 0.05
15	18123 + 0511	15/09/94	2.10 ± 0.15	4.82 ± 0.45	3.33 ± 0.50
	,,	17/09/94	1.21 ± 0.04	3.71 ± 0.15	2.90 ± 0.06
	,,		**1.66 ± 0.63**	**4.27 ± 0.78**	**3.12 ± 0.30**
16	18599 + 2246	16/09/94	1.12 ± 0.22	1.86 ± 0.66	1.48 ± 0.71

The values in bold print are the averages obtained from the observations taken on different dates, when observations have been carried out on the same source on at least two different dates.

In Table 1 we list the IRAS PSC data on these sources along with their J and V magnitudes from the Guide Star Catalog (GSC version 1, 1989: Jenkner *et al.*, 1990; and Lasker *et al.*, 1990). In Table 2 we list sequentially in columns 1-6, the serial number of the source, the IRAS name of the source, the date of observation, and the equivalent widths of the Ca II triplet lines λ8498, λ8542, and λ8662 (in Å). When observations are available on more than one night for any source, the mean values of the equivalent widths from the observations on different nights are listed in bold print.

3. Discussion

The data on the equivalent widths of the Ca II triplet lines are presented in Table 2. The equivalent widths listed in the table are the mean values of the equivalent widths determined from a single spectrum using windows of several sizes around a mean value of 10 Å. The errors quoted on the mean values are the root mean square (r.m.s) errors on the equivalent widths obtained using different window sizes. When observations on more than one night are available the equivalent widths and the errors on them (shown in bold print) are the mean of the values obtained on the different nights and the r.m.s. errors on them. The programme sources can be divided into three categories: i) sources with the sum of the equivalent width of their Ca II triplet lines >5 Å, ii)sources with the sum of the equivalent width of their Ca II triplet lines < 5 Å and iii) the source IRAS 04184 + 2008 which indicates profile variations and also strong variations in the equivalent width of the Ca II lines over the period of our observations. Sources with the sum of the equivalent width of their Ca II triplet lines > 5 Å are likely to be stars (Giants or Supergiants) with normal calcium abundance. Sources with the sum of the equivalent width of their Ca II triplet lines < 5 Å are likely to be stars of i) very early type (if the sum of the EQW is low after correcting for the contribution from Paschen lines which occur in the vicinity of Ca II triplet lines), ii) very late type stars where the TiO has depressed the continuum completely, iii) of high log g, iv) very metal poor or some combination of the last three. The spectrum of IRAS 04184 + 2008 is unique in itself and does not resemble those of any other programme sources. It appears to be chromospherically active. Equivalent width data of Ca II triplet lines of very early type stars MK standards (earlier than F8) are taken from Danks and Dennefeld (1994) and of stars later than F8 to M4 from Mallik (1994) for purposes of calibration and to compare the equivalent widths of the Ca II lines and their ratios λ84542 / λ8498 and λ8542 / λ8662,of stars observed by us.

We discuss below the programme sources individually under the above three classifications and compare the measured total equivalent width and the equivalent width ratios with values expected for these quantities on the basis of the available data (Danks and Dennefeld 1994; Mallik 1994). Presented in Figures 1-6, are the spectra of the sources observed by us.

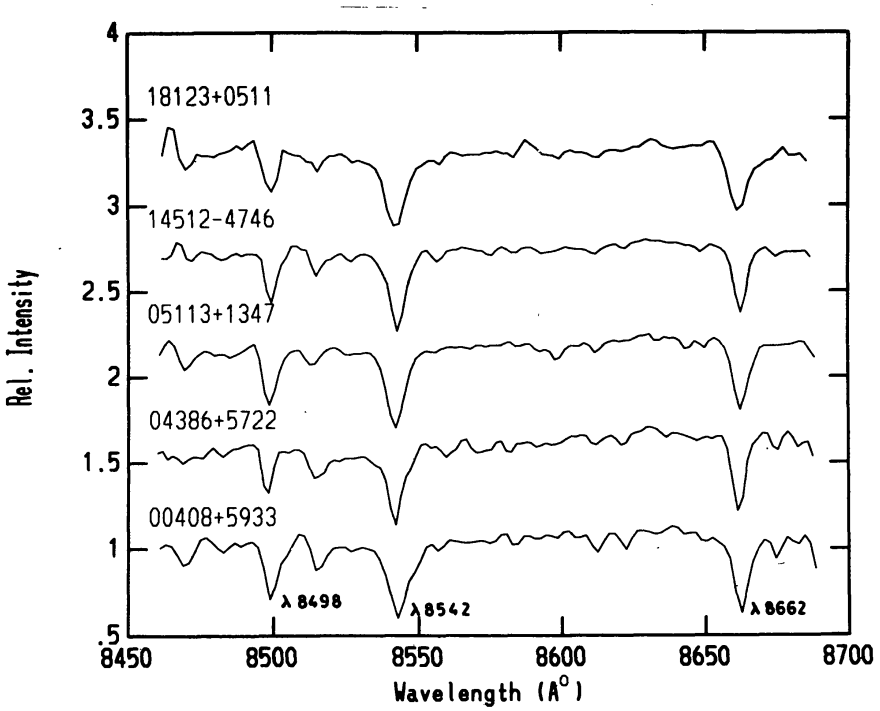

Figure 1. Spectra of IRAS sources 00408 + 5933, 04386 + 5722, 05113 + 1347, 14512 – 4746 and 18123 + 0511 in the $\lambda\lambda$8460 – 8690 Å range. The intensities are normalised to the intensity at a wavelength of 8460 Å. The spectrum of each source is shifted w.r.t the previous one by 0.6 unit along the ordinate axis.

3.1 Sources with the sum of the equivalent width of their Ca II triplet lines > 5 Å

#1 IRAS 00408+5933

The IRAS [12]-[25] and [25]-[60] colours of this source exclude it from being classified as either an (infrared) bright star, oxygen-rich star or a carbon-rich star (Walker and Cohen, 1988). Iyengar and Parthasarathy (1997) tentatively found it to be a variable star. They also adduce data from a study of the image of the counterpart of this source on the Palomar Observatory Sky Survey (POSS) prints to show that it is far brighter on the E print than on the O print. It thus appears to be a comparatively cool source. Our data on the equivalent width of the Ca II triplet lines of this source indicate it to have a very large value for the sum of the equivalent width of these lines. This suggests it to be a giant star with normal calcium abundance. IRAS PSC did not associate this source with a source in any of the 29 catalogues searched for counterparts (of which the General Catalogue of Variable Stars (GCVS) by Kukarin was one of them). It could however, be the LB variable V447 Cas (SIMBAD database). The observed large value for the sum of the equivalent width of the Ca II triplet lines is in conformity with its being an LB variable.

#4 IRAS 04386+5722

The data on the equivalent widths of the Ca II triplet lines presented in Table 2, show that the equivalent width (EQW) ratios of λ8542 / λ8498 and of λ8542/λ8662 of Ca II lines have the values 1.82 ± 0.29 and 1.24 ± 0.17. These are within the range of values (Mallik 1994) expected for most stars. The sum of the EQW of all the 3 lines of the triplet is 7.50 ± 0.44 Å. It thus appears to be a star with almost normal abundance of heavy elements. The IRAS [12]-[25] and [25] - [60] colours of this source indicate it to be an oxygen-rich star (van der Veen and Habing 1988). Blommaert *et al.* (1993) who carried out near infrared photometric observations of this source and also analysed available molecular line observational data conclude that this source is not an AGB star.

#5 IRAS 05089+0459

The spectrum of this source presented in Figure 2 shows that it is noisy and that the Ca II triplet lines are not distinct and strong. However, the λ8498 Å and λ8542 Å lines seem to appear in absorption. The λ8662 Å line is not distinguishable from the background features. The spectrum of this source is seen to be unlike that of any other source discussed in this paper. The star appears brighter on the POSS E print than on its O print. The far-infrared emission from this source peaks at 25 μm and the dust emission corresponds to a temperature

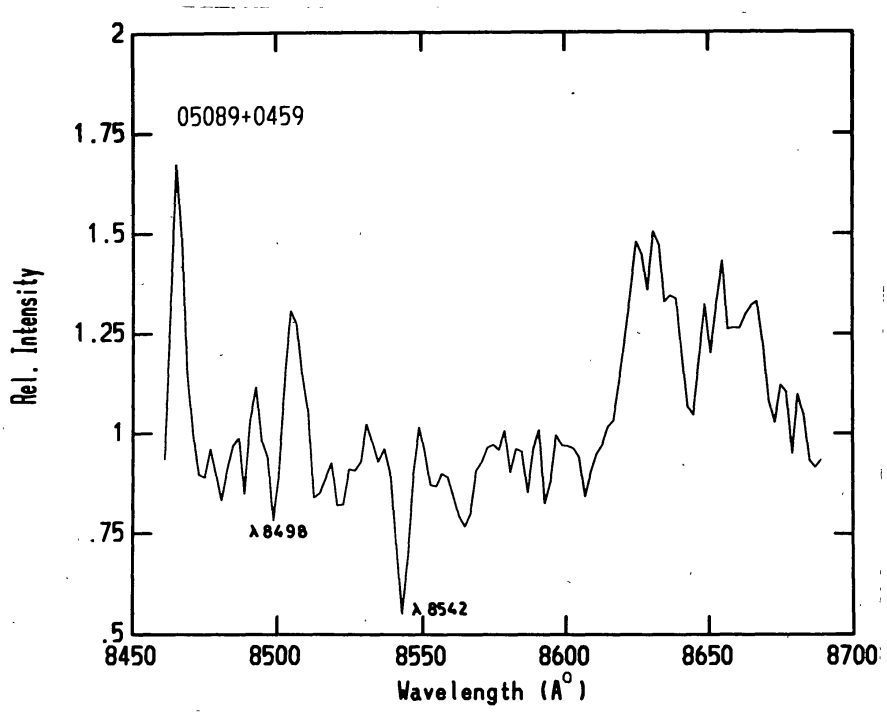

Figure 2. Spectrum of IRAS source 05089 + 0459 (as same in Figure 1).

of about 200 K. Its position in the [25]-[60] versus [12]-[25] colour-colour diagram of van der Veen and Habing (1988) indicates it to be either wholly or partly obscured by circumstellar dust and in the AGB phase evolving at a high mass loss rate. Hu *et al.* (1993, 1994) refer to this source as a protoplanetary nebular (PPNe) candidate.

#6 IRAS 05113+1347

Hrivnak *et al.* (1994) have carried out H, K and L band low-resolution infrared spectroscopic observations of this source. They assign it a spectral type G8Ia. Hrivnak (1995) carried out medium resolution (2.6 Å) spectroscopic study of this source in the range λλ3872-4870 Å. He finds C_2 and C_3 absorption features and also absorption lines due to S process elements to be quite strong in the spectrum of this source. He notes that the object appears to have normal metal abundance. The equivalent widths of the Ca II triplet lines, determined from our observations are presented in Table 2. The equivalent width ratios of λ8542 / λ8498 and of λ8542 / λ8662 are 2.20 ± 0.20 and 1.40 ± 0.16, respectively, and the sum of the EQW of all the three lines is 7.72 ± 0.33 Å. Thus these two EQW ratios and the sum of the EQWs of the three lines together are fairly well within the range of these values observed for most normal stars. It thus seems to be an evolved star with normal abundance of heavy elements. The observed equivalent widths of the Ca II lines thus appear to be reasonably consistent with the spectral type assigned by Hrivnak *et al.* (1994). A G8Ia star is generally expected to show wide Ca II line profiles with emission features etc., in the core of its absorption lines. The spectrum of the source shown in Figure 1 however, does not show any such sharp details and may be due to the low resolution used for obtaining these spectra.

#9 IRAS 14512-4746

The IRAS [12]-[25] and [25]-[60] colours of this source indicate it to be an oxygen-rich star (Walker and Cohen, 1988). It is identified with a star HD 131341 with B and V magnitudes of 11.1 and 9.3 respectively, and spectral type M5III (Houk). Our spectroscopic observations of this source yield for the EQW ratios of λ8542 / λ8498 and λ8542 / λ8662 Ca II triplet lines the values 2.20 ± 0.33 and 1.43 ± 0.16, which are very similar to values expected for stars of normal metal abundance. The sum of the EQW of the 3 lines together is equal to 6.50 ± 0.34 Å and is thus less than that expected for stars of normal metal abundance.

#15 IRAS 18123+0511

The EQW ratios of λ8542/λ8498 and of λ8542 / λ8662 of this source have values 2.57 ± 1.08 and 1.37 ± 0.28 which are within the range of values found for most stars. The sum of the EQW of all three lines is 9.05 ± 1.05 Å and it thus appears to be a giant or supergiant star with normal calcium abundance. It is identified with V2053 Oph (SIMBAD database). However, no information is available on its spectral type.

3.2 Sources with the sum of the equivalent width of their Ca II triplet lines < 5 Å

#2 IRAS 04101+3103

This source is identified with HDE 281789 (SIMBAD database) of spectral type AO. It has been assigned spectral type Ale and is called a pre-main-sequence star by Kenyon *et al.* (1990).

The Ca II triplet lines from this source are broad. The spectrum of this source is presented in Figure 3 along with that of IRAS 05245+0022, as the spectrum of the two sources resemble very closely one another. Both these sources show wide absorption features in the region of Ca II triplet lines and also a broad spectral feature at λ8600 Å which we identify with P14 (Paschen series line in the spectrum of hydrogen). It is therefore obvious that there should also be the other lines of the Paschen series viz., P16, P15, and P13 occuring in this region of the spectrum which fall within a few Å of the calcium lines. The equivalent width of these blended lines observed in the region of Ca II lines is therefore to be corrected to account for the contributions to their widths from their neighbouring Paschen lines. The contributions of the Paschen lines to their nearby calcium lines were computed using our observational data on the equivalent widths of the P14 (λ8598.39) and P12 (λ8750.47) lines with the f_{ik} values tabulated by Weise *et al.* (1966) to relate them to relevant transitions and to obtain the scale factor (equivalent width versus f_{ik}) required to convert the f_{ik} values of the other Paschen lines to equivalent widths (Danks and Dennefeld 1994). These corrected widths are presented in Table 2. It is seen that the equivalent widths of the Ca II lines are either very low or negligible

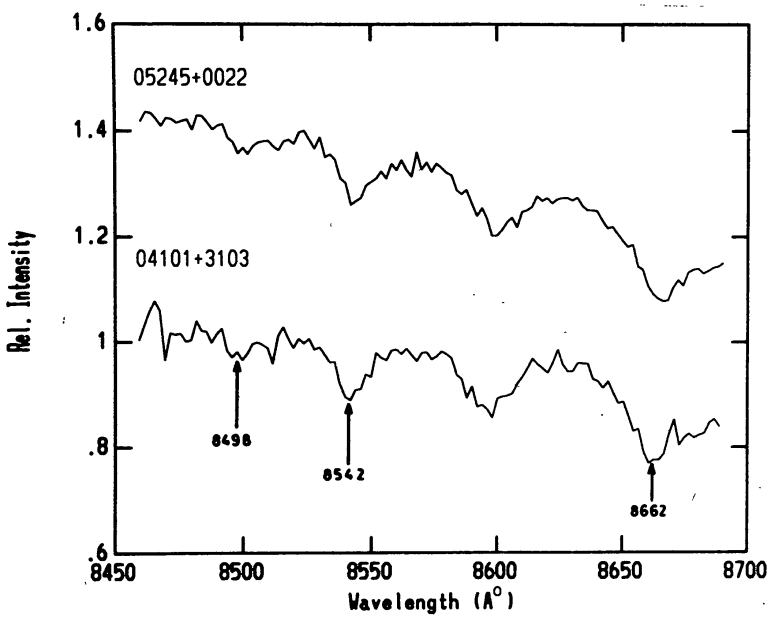

Figure 3. Comparison of the spectra of IRAS sources 04101 + 3103 and 05245 + 0022, (same as in Figure 1). The spectrum of 05245 + 0022 is shifted w.r.t. that of 04101 + 3103 by 0.4 unit along the ordinate axis.

(within the errors of measurement which are no doubt large). There may be some emission at λ8498 line of the Ca II triplet. The observed low equivalent widths of the Ca II lines of this source are in conformity with it being an early A type star.

#7 IRAS 05245+0022

Torres *et al.* (1995) carried out i) optical photometry and ii) spectroscopic observations of this source in the spectral range 651-673 nm covering the H_α and 670.8 nm Li lines of this source. They obtained UBVRI magnitudes of 10.20, 10.11, 10.02, 9.96 and 9.89. They classify it as a new and suspected Herbig Ae/Be star. They measure an equivalent width of 6 Å for the H_α line. They identify this source with HD 290409 and Guetter (1981) gives its spectral type as B8.5 Ve. The spectrum of this source is presented along with that of IRAS 04101 + 3103 in Figure 3, for purposes of comparison. It is seen that the lines in the region of Ca II triplet are broad as in the case of IRAS 04101+3103 and appear to result from the blending of the Paschen lines P13, P15, and P16 with the Ca II triplet lines which occur within a few Å of the calcium lines. The equivalent widths of the Ca II triplet lines were computed using the same procedure as detailed earlier in the case of IRAS 04101 + 3103. These corrected widths are presented in Table 2. There may be some emission at λ8498 line of the Ca II triplet. However, the low or near negligible value for the sum of the equivalent widths of the Ca II triplet lines appear to be consistent with its being a late B type star.

#8 IRAS 12387-3717

We have measured the equivalent widths of the Ca II triplet lines of this source and find that the equivalent widths of all the three lines are about the same, indicating a deviation in the ratio of intensities expected for these lines (Mallik 1994). The sum of EQW of all the three lines together is 2.07 ± 0.14 Å, very low compared to those of stars of normal metal abundance. This could either be due to low metallicity of this star or that Ca II may not be the dominant ionization species.

#10 IRAS 15269-4400

Our data from spectroscopic observation of the Ca II triplet lines of this source yields a value of 3.34 ± 0.16 Å for the sum of the EQW of all the three lines. This value is very low compared to the value of the same parameter in stars of normal metal abundance. However, the EQW ratios of λ8542 / λ8498 and of λ8542 / λ8662 have values 1.65 ± 0.13 and 1.08 ± 0.13 which are fairly close to the ranges of values expected for these ratios for normal stars.

#11 IRAS 17173-4632

The spectroscopic observation of this source in the region of the Ca II triplet line shows the EQW of each of the three lines of the triplet to be very low and the total equivalent width of the lines to be 3.27 ± 0.23 Å (a value lower than expected of stars of normal metal abundance). However the EQW ratio of λ8542 / λ8498 has the value of 1.51 ± 0.16 (almost within the normal range) but the EQW ratio of λ8542 / λ8662 has a value of 0.85 ± 0.14 lower than the

value found in most stars. MacConnell (1996) classifies it as a star of spectral type M6.5 from low-dispersion near-infrared objective prism spectrum of this source. This classification is in conformity with the low value obtained by us for the sum of the equivalent widths of the three Ca II lines. However, no data is available on the luminosity classification of this source.

#12 IRAS 17174-4641

The EQW ratios of λ8542 / λ8498 and of λ8542 / λ8662 of this source are 2.65 ± 0.27 and 1.52 ± 0.17. These values are within the range of the expected values of these ratios for most stars. However, the sum of the EQW of all three lines is 3.34 ± 0.23 Å only and is much lower than that expected for stars of normal metal abundance. MacConnell (1966) classifies this as a star of spectral type M7. The low value for the sum of the equivalent width of the three Ca II lines obtained from our measurement is in conformity with MacConnell's classification.

#13 IRAS 17201-4613

The sum of the EQW of all the three Ca II triplet lines from our observations of this source is 3.87 ± 0.15 Å, and is again low compared to that of most stars of normal metal abundance. The EQW ratio of λ8542 / λ8498 is 1.81 ± 0.17 and is within the range of normal values but the EQW ratio of λ8542 / λ8662 is 0.84 ± 0.08 which is lower than the value of 1.2-1.4, normally observed in most stars. It is identified with HD 157144 (SIMBAD database) and its spectral type is M6III (Houk 1982).

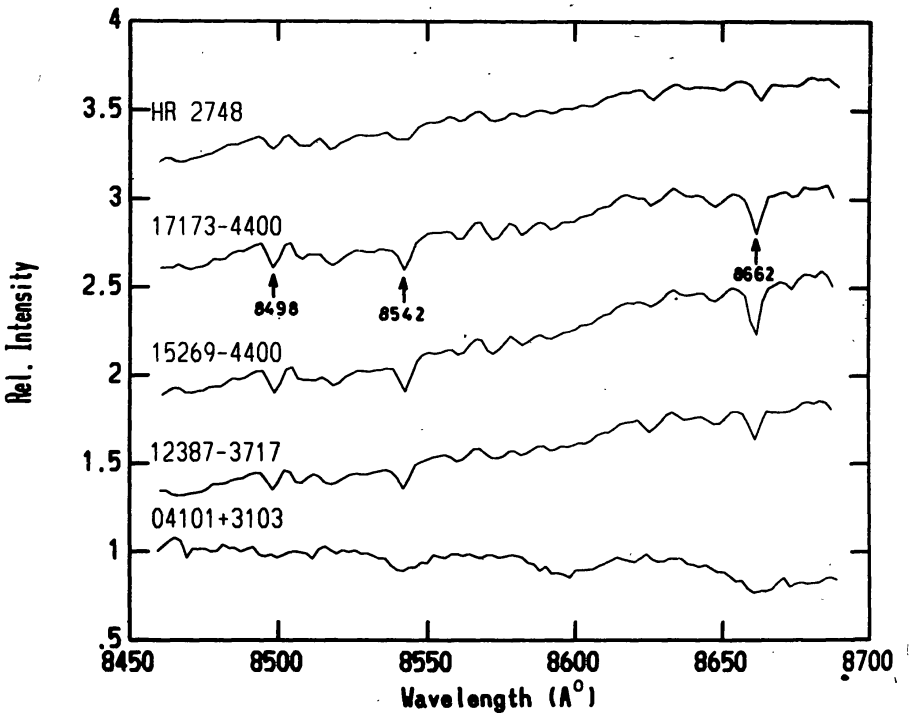

Figure 4. Spectra of IRAS sources 04101 + 3103, 12387 – 3717, 15269 – 4400 and 17143 – 4632 and HR 2748 (as in Figure 1). The spectrum of each source is shifted w.r.t. the previous one by 0.6 unit along the ordinate axis.

#14 IRAS 17318-3606

It is seen from the data presented in Table 2, the EQW ratios of λ8542 / λ8498 and of λ8542 / λ8662 of the Ca II triplet lines are 2.00 ± 0.59 each, and thus almost within the range of values found for these ratios in most stars. However, the EQW of all the three lines of the triplet together is only 1.84 ± 0.26 Å. This star is identified with the M8 star No. 8-382 in Table 4 of Raharto *et al.* (1984). MacConnell (1996) classifies it as a star of spectral type M7.

#16 IRAS 18599+2246

Our spectroscopic observations of the equivalent width of the Ca II triplet lines of this source yield for the EQW ratios of λ8542/λ8498 and of λ8542 / λ8662 the values 1.66 ± 0.67 and 1.26 ± 0.75. These are fairly well within the range of values expected for stars of normal metal abundance. However, the sum of the EQW of all the three lines of the triplet is only 4.46 ± 0.99 Å, a value much lower than that found in most stars of normal metal abundance. The IRAS [12]-[25] and [25]-[60] colours of this source indicate it to be a bright star as per the classification by Walker and Cohen (1988). Presented in Figure 4, are the spectra of the IRAS sources 04101+3103, 12387–3717, 15269–4400 and 17173–4632 along with the spectrum of HR 2748 (a star of spectral type and luminosity class M6IIIe) for purposes of comparison and in Figure 5, the spectra of IRAS sources 17174–4641, 17201–4613, 17318–3613 and 18599+2246. It is seen that the spectra of all these sources (save IRAS 04101+3103) look very similar to one another in the wavelength range λλ8460–8690 Å and that their intensity increases with wavelength. Their spectra also appear to be similar in type to that of HR 2748 (a star of spectral type M5IIIe). We conclude from the similarity of the spectra of these 7 sources that they are all cool stars of very nearly the same spectral type (later than M5).

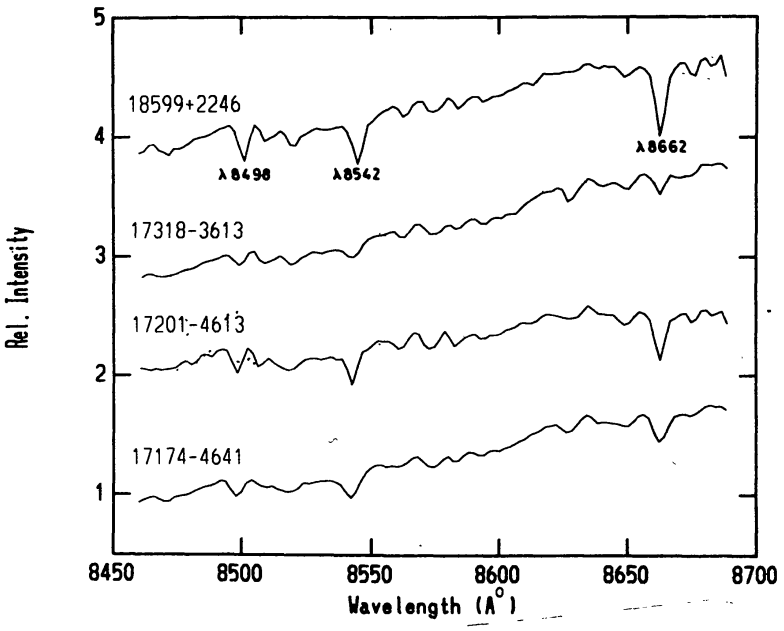

Figure 5. Spectra of IRAS sources 17174 – 4641, 17201 – 4613, 17318 – 3606 and 18599 + 2246 (as in Figure 1). The spectrum of each source is shifted w.r.t. the previous one by 1.0 unit along the ordinate axis.

It is likely that the low equivalent widths of the Ca II triplet lines of the sources discussed in this section may be due to depression of the continuum in the region of the Ca II triplet lines by intense absorption from TiO bands which can occur in their vicinity.

IRAS 18599+2246 is identified with HD 177025 same as PPM 108262 (SIMBAD database). It happens to be star No. 17313 in the Dearborn Observatory Catalogue of red stars (Lee and Bartlett 1944), where its spectral type is given as M6. MacConnell (1996) notes that it has a small proper motion of 0.028 arcsec yr^{-1} which happens to be inconsistent with it being a supergiant although it does not exclude it from being a giant. However, it does not have a good MK spectral type assignment as Houk (1982) has not yet classified the HD stars this far north.

3.3 Chromospherically active source

#3 IRAS 04184+2008

Stephenson(1986) assigns a spectral type > M6 and V> 13.5 to this star from an examination of its spectrum in the $\lambda\lambda$5000-6000 Å region obtained at a dispersion of about 1000 Å mm^{-1} at H_α. Cohen *et al.* (1989) have assigned it a spectral type M on the basis of its spectrum in the range $\lambda\lambda$4700-7400 Å obtained with a resolution of 11 Å. Iyengar and Parthasarathy (1996) suggest for it a spectral type M5 or later based on its location in the (V-I) versus (B-V) colour-colour diagram. Our spectroscopic observation of this source in the region of H_α line shows it in emission. We have carried out spectroscopic observations of this source in the

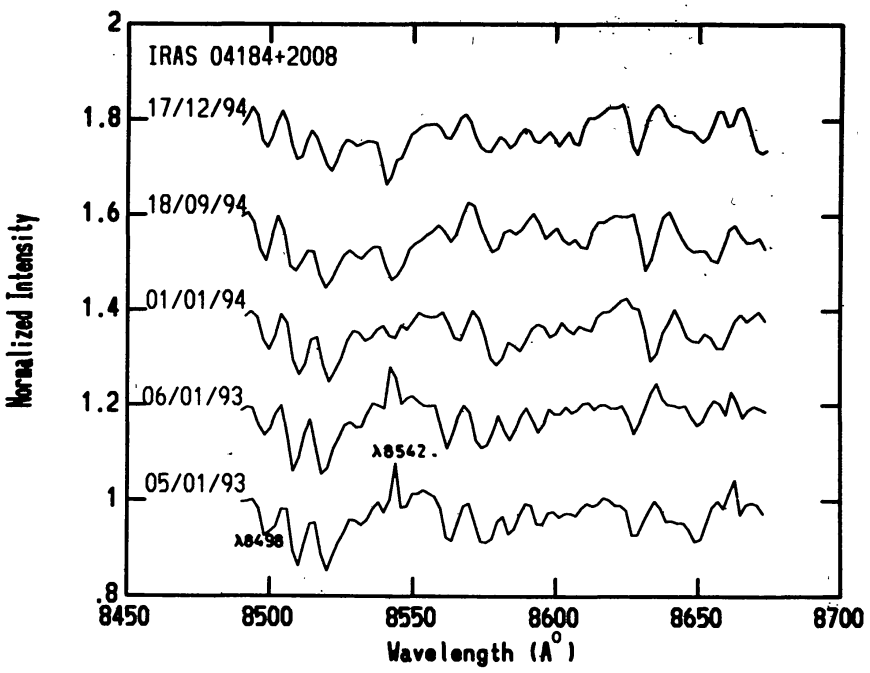

Figure 6. Continuum normalized spectra of IRAS sources 04184 + 2008 obtained at the epochs indicated against them (as detailed in the text). The spectrum obtained on the different dates are shifted w.r.t. one another.

wavelength region λλ8200-8800 Å on 5 different nights extending over a period of about 2 years. The continuum normalised spectra of this source obtained on the different nights are presented in Figure 6. It is seen that the λ8498 Å line of Ca II triplet is always seen in absorption, whereas the λ8542 Å is seen in emission in the two earlier epochs but in absorption at the later epochs. No distinct feature corresponding to λ8662 Å is seen in the spectra. The profiles of these spectra in the vicinity of the λ8662 Å line show variation from epoch to epoch. The source has a variability index of 9 (IRAS PSC, 1988) which is a measure of the high degree of its variability in the far-infrared. The optical photometric data (Iyengar and Parthasarathy 1997), seem to bear this out. The variation in the equivalent widths and profiles of the Ca II triplet lines indicate this source to be chromospherically very active. This is identified by Kaiser (1995) with a Mira type variable star of magnitude ranging from 12.5 to < 15.5 p, period ~322 days and spectral type M. He assigns it the variable designation DHK 42 (=GSC 1272.0567).

4. Conclusions

We have determined the equivalent width ratios of λ8542/λ8498 and of λ8542 / λ8662 and the total equivalent width of the Ca II lines of 16 'unidentified' IRAS sources of a late type stellar nature. The IRAS sources 00408+5933, 04386+5722, 05113+1347, 14512–4746 and 18123+0511 have a total equivalent width ≥ 6.5 Å. These therefore appear to be late type giants or supergiants with normal calcium abundance in their atmospheres. The remaining sources have a total equivalent width less than 5 Å. However, since they are detected by IRAS and have a high degree of far-infrared emission, they are likely to be stellar sources in an advanced stage of evolution. The low equivalent widths of their Ca II lines seems to suggest that most of the calcium is in neutral form Ca I instead of in Ca II as is expected to be in stars of very late M types.

Both IRAS 04101+3103 and IRAS 05245+0022 appear to be Herbig Ae/Be stars of spectral type Ale and B8.5e, respectively.

The spectra of IRAS sources 12387-3717, 15269–4400, 17173–4632, 17174–4641, 17201–4613, 17318–3606 and 18599+2246 closely resemble one another and also that of 17201–4613 which has been identified as an M6III star. Their spectra also appear to be similar to that of HR2748 of spectral type and luminosity class M5IIIe. They all thus appear to be stars of spectral type M5 or later.

IRAS 04184+2008 appears to be chromospherically very active as the equivalent widths of its Ca II triplet lines indicate strong variations during our observations covering a period of two years. It is identified to be a variable star of Mira type designated as DHK 42 (Kaiser 1995).

Observations of other charactersitic metallic lines are required to verify whether the observed low equivalent widths of Ca II triplet lines are indeed due to i) low metallic abundance or ii) filling up of the continuum in the region of the Ca II lines by TiO bands (resulting in low values for the equivalent width of the Ca II lines) or iii) Ca II not being the most abundant ionization species.

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