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The Ca II triplet lines in cool stars

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Abstract. — Observations of the infrared triplet lines of ionized calcium are presented for 91 stars brighter than $m_v = +7.0$ in the spectral range F8-M4 of all luminosity classes and over a range of metallicities [Fe/H] from −0.65 to +0.60. The above spectra have been obtained at a spectral resolution of 0.4 Å with a coudé echelle spectrograph using the Thomson CCD as the detector. This study has been undertaken primarily to investigate the dependence of the Ca II triplet strengths over the broad range of atmospheric parameters like luminosity, temperature and metallicity. The Ca II triplet lines are a powerful diagnostic of the stellar populations in galaxies because of their sensitivity to the above parameters. Our detailed analysis indicates a strong correlation between the equivalent width of the Ca II triplet lines and surface gravity, much stronger in metal rich stars than in metal poor stars. The Ca II equivalent widths are fairly insensitive to temperature over the range of luminosity covered. However, they are found to be quite sensitive to metallicity, more conspicuously in supergiants than in giants and dwarfs. Observations are compared with recent theoretical calculations of these lines in NLTE atmospheres.

Key words: stars: atmospheres – stars: late-type – galaxies: stellar content

1. Introduction

The old stellar populations and the nuclei of galaxies are dominated by G, K and M stars and therefore emit bulk of their light in the near infrared region of the spectrum. The most conspicuous feature of this part of the spectrum is the Ca II triplet at λλ 8498, 8542 and 8662 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 which are most likely radiatively populated. There are other important features in the near infrared, e.g., Na I λλ8183, 8195 that have been explored in the past but their usefulness has been somewhat limited as they are drowned in the telluric H_2O lines. The Ca II triplet lines are comparatively free from blends, are not contaminated seriously by the atmospheric absorption lines and are fairly strong even in fainter stars and stellar systems. All this makes them potentially powerful tools for the study of stellar populations in galaxies once we quantitatively understand and then exploit their dependence on the stellar atmosphere parameters like luminosity, effective temperature and metallicity.

The question of whether or not the stellar content in galaxy nuclei is dwarf-enriched has been discussed for over a decade. For a more recent discussion, see Frogel (1988). Faber & French (1980) interpreted the strength of the luminosity-sensitive red Na I doublet at λλ8183, 8195 in the spectrum of M 31 as evidence for an enhanced population of dwarfs which confirmed the result of Spinrad & Taylor (1971) that the light from the nuclei of M 31 and M 81 is dominated by dwarfs. The work of Carter et al. (1986) on several galaxies based particularly on the strength of the Na I doublet also suggests that the light from these galaxies comes predominantly from cool dwarfs. Cohen (1978), however, interpreted the measurements of the Na I doublet in terms of metallicity enhancement rather than dwarf light enhancement. Whitford (1977) measured the strength of the Wing-Ford band at 9910 Å in a number of galaxies and found it to be very weak implying the absence of late M dwarfs and probably favouring a giant-dominated population in the nuclei of M 31 and other early type galaxies. Jones et al. (1984) interpreted the strength of the Ca II triplet absorption feature in M 31 and M 32 measured by Cohen (1979) and Faber & French (1980) as indicating that the light near 8550 Å is dominated by giants rather than dwarfs and that the strength of the Na I doublet is due to metallicity or some parameter other than luminosity. The interpretation of an observed strong-lined spectrum in terms of a super metal rich population is not straightforward either. Thus the problem of whether the nucleus of a galaxy or any stellar system is dwarf enriched and/or super metal rich is still ridden with controversies.

In further attempts to resolve these controversies, in recent years a good deal of research, both theoretical and observational has especially gone into the determination of the sensitivity of the Ca II triplet strength to the parameters $T_{\rm eff}$, log g and chemical composition. With the advent of CCD detectors, it has been possible to observe the Ca II triplet rather easily in a wide variety of stars, stellar systems and galaxies. The recent observational studies include apart from Jones et al. (1984, hereafter JAJ) and Carter et al. (1986), Alloin & Bica (1989), Diaz et al. (1989, hereafter DTT) and Zhou (1991). JAJ observed the Ca II triplet in 62 stars ranging in spectral type from early B to mid M over 4 orders of magnitude in surface gravity and a factor of 10 in metallicity with a spectral resolution R of 3 Å. Examination of their extensive data revealed the existence of almost a single valued relation between the Ca II triplet equivalent widths and log g for all stars ranging from the spectral type F through mid M. Since most of the light from galaxies is thought to come from G and K stars, their study implied that the Ca II triplet feature should thus be a useful discriminant for the dwarf/giant ratio of the light- dominant stellar population. From their detailed study of the Ca II triplet in stars, star clusters and galaxy nuclei, Alloin & Bica (1989) concluded, however, that the Ca II triplet has a significant dependence on metallicity too. More recently, these lines have been studied by DTT in 106 stars with $R = 3.5$ Å and by Zhou (1991) in 144 stars with $R = 2$ Å. They have also suggested that the Ca II strengths depend both upon gravity and metallicity. They concluded that in the high metallicity range, Ca II strength depends on gravity alone. Therefore, it is a good estimator of luminosity in metal rich systems. In the low metallicity range, however, Ca II strength depends much less strongly on log g and the metallicity dependence is more prominent.

There have been a number of theoretical studies too to evaluate the effects of $T_{\rm eff}$, log g and chemical composition on the Ca II triplet (Smith & Drake 1987, 1990; Erdelyi-Mendes & Barbuy 1991, Jørgenson et al. 1992, hereafter JCJ). Smith & Drake and Erdelyi-Mendes & Barbuy calculated synthetic spectra for the Ca II lines in the LTE approximation using model atmospheres computed by MARCS code. Since they did not include the computation of the line core, equivalent widths could not be generated, instead only a width parameter could be obtained. As a result, they could not compare their results directly with the observed equivalent widths. More recently, JCJ have carried out non-LTE calculations spanning a large range in parameter space, $T_{\rm eff}$: 4000 − 6600 K; log g : 0.00 − 4.00 and calcium abundance [A/H]: (+0.2)-(-1.0) and calculated the equivalent widths (EQW) of the Ca II triplet to test their sensitivity to surface gravity, effective temperature and calcium abundance. These theoretical results can now be compared with observations. These authors concluded from their study that the EQW (which denotes the sum of the two lines λ8542 and λ8662) decreases rapidly with increasing log g for giants and supergiants whereas the relation is flatter for dwarfs. This result qualitatively matches that of Erdelyi-Mendes & Barbuy (1991). The dependence is exponential and not linear and this trend becomes evident only when a large parameter space is covered. In agreement with the observations of DTT, their calculations show that the relative dependence of EQW on log g is strongest for high metallicity systems. The integrated spectra of Ca II lines could thus lead to useful information on luminosity in high metallicity systems. Also, there is a fairly strong dependence of the Ca II EQW on metallicity and is much stronger for giants and supergiants than for dwarfs. The relationship once again is not linear. It is much stronger for metal rich stars. The biparametric behaviour is thus much more pronounced for higher metallicities. 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 $T_{\rm eff}$ and that giants and dwarfs respond differently to the changes in metallicity.

In view of the above complex behaviour of the Ca II EQW on the parameters $T_{\rm eff}$, log g and [Fe/H] as demonstrated by both observational and theoretical studies, we decided to reinvestigate this problem from the observational point of view; in particular to compare our observed EQW's with the theoretically computed values of JCJ for the corresponding sets of parameters.

The observations and the data reduction are described in Sect. 2. Section 3 discusses the behaviour of the Ca II triplet strength with respect to various stellar atmospheric parameters. Conclusions are given in Sect. 4.

2. Observations and data reduction

We have sampled a large number of cool stars brighter than $m_v = +7.0$ and of all luminosity types ranging in spectral type from F8 to M4 from the Bright Star Catalogue (Hoffleit 1982) and the [Fe/H] catalogue of Cayrel de Strobel et al. (1985). The observations were acquired using the coudé echelle spectrograph at the 102-cm telescope of Vainu Bappu Observatory, Kavalur with a CCD detector having the format 384×576 pixels, each pixel of size 23μ square. A 150 ℓmm^{-1} cross dispersion grating blazed at 8000 Å in the 1st order, particularly suited for observing the Ca II triplet, was used in conjunction with the 79 ℓmm^{-1} grating and a 25-cm camera. The above configuration yielded a dispersion of about 9 Åmm^{-1} in the 26 th order where the Ca II triplet lines lie. This coupled with the slit width used gave a spectral resolution of about 0.4 Å. This resolution is much higher than the ones used in the previous studies. Our aim has been to ensure a more accurate determination of the line strengths. We have observed λλ8498, 8542 in about 91 stars so far, spanning 4 orders of magnitude in g, a factor of 15 in metallicity and a spectral type range from F8 to M4. λ8662 requires a different setting of the echelle grating and the cross disperser and has been observed in only 17 stars. Signal-to-noise ratio in most of the spectra has been 50-100. For a few cases, more than one star frame was obtained and coadded to produce a better signal/noise ratio. A Thorium-Argon hollow cathode lamp was used for line identification and wavelength calibration and a Xenon lamp was used as a flat field source. A good number of bias, comparison and flat field frames were taken well spaced out in time each night.

Table 1 gives the known stellar parameters of the program stars taken from the Bright Star Catalogue and the [Fe/H] catalogue of Cayrel de Strobel et al. (1985). Columns 5 and 6 give respectively $T_{\rm eff}$ and (R-I). (R-I) is a very good temperature indicator for cool stars. The values of log g and [Fe/H] have been adopted from the [Fe/H] catalogue. When more than one metallicity was given, care was taken to adopt the average of the best quality data, i.e., data obtained at high resolution and/or in red/near- infrared. These data are deemed more reliable because the red region is less crowded than the blue, thus minimizing the effects of blanketing and allowing a better location of the continuum. There are several stars chosen for which [Fe/H] and log g are not yet available in literature. Wherever log g is not available, we have used the statistical values given in Allen (1973) and Zhou (1991).

Data reduction was carried out with the 'RESPECT' software package due to Prabhu & Anupama (1991) installed at the Vax 11/780 system at VBO. Here, the method of extraction of one-dimensional spectra from the two dimensional CCD image is based on the optimal extraction algorithm developed by Horne (1986, 1988). 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 which corrected both for the pixel to pixel sensitivity difference of the detector and for the curved nature of the response function of the echelle spectrograph across each order. Since the present study of the Ca II triplet lines involved the measurement of equivalent widths, no flux calibration was performed. Instead, each observed spectrum was divided by an estimated continuum. 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 most of the previous studies has been 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 lines has the effect of eliminating the contribution from the wings of the Ca II lines which results in underestimating the EQW whereas choosing a straight line continuum between local maxima far to the right and left side of the Ca II line results in an overestimate of the EQW because of the inclusion of TiO bands which appear in the vicinity of the Ca II feature stretching from 8432 Å to 8620 Å. The TiO bands with the triple bandheads at λλ8432, 8442 and 8452 become very strong for stars of spectral types M4 and later and tend to depress the continuum and make the Ca II triplet lines look weaker. We have very few M stars in our list, in fact none later than M4; so this problem was not very serious. To locate the continuum, a few points were chosen consistently for all the stars in the regions relatively free of lines across the order containing the λ8498 and λ8542 lines. This was possible because the observations were obtained at a fairly high spectral resolution. Continuum fitting with a choice of selected points leading to a lower continuum level yielded lower EQW measures. The error in the EQW measures based on the choice of continuum points was around 5 per cent. From the data for stars observed more than once, the error in the determination of EQW's for each individual observation could be estimated and this turns out to be less than 10 per cent. Columns 3 and 4 of Table 2 list the EQW's of the Ca II lines λ8498 and λ8542. In Col. 5, it also lists the EQW of λ8662 for the stars for which it was possible to observe it. For the stars in common with DTT, our values are systematically lower than theirs roughly by 15 to 20 per cent and for those in common with Zhou (1991), the values differ by an average of 35 per cent. However, our λ8498 EQW measures of 11 stars in common with Anderson's (1974) work are higher than his and our λ8542 measures of 19 stars in common with Linsky et al. (1979) are also higher than theirs. These differences may partly be due to the choice of the continuum. A more important reason for these differences lies in the choice of the line window for the measurement of EQW of the three lines. DTT chose a 30 Å window around each line and computed the EQW's of the Ca II triplet by integrating the flux inside this window and dividing it by the local continuum at the center of each line. EQW measurements of the Ca II triplet by Zhou (1991) have been based on a choice of line window of 20 Å. As a consequence, several features of Ti I, Fe I, Si I, Ni I and CN either blended with a Ca II triplet line or on either side of it have contributed to the resultant EQW. Owing to a much higher resolution in the present study, we have limited to a much smaller window for each of the Ca II triplet lines determined roughly by where the line wings merge with the local continuum. The line windows chosen are 8495-8501 for 8498 Å; 8535-8550 for 8542 Å and 8656-8669 for 8662 Å. Because of the smaller windows, there is much less contamination from the neighbourhood of the Ca II triplet, thus yielding much lower EQW's.

In view of the absence of the observation of λ8662 for all the stars, in the discussion that follows, the EQW of Ca II will refer to the sum of the EQW's of the two lines λλ8498, 8542 called 'Ca T' and tabulated in Col. 6

of Table 2. The sum is taken to improve the S/N ratio and eliminate the influence of irrelevant lines. The observational data of DTT, JAJ and Zhou (1991) suggest that on an average the EQW ratio of $\lambda8542/\lambda8498$ lies between 2.1 - 2.5 and that of $\lambda8542/\lambda8662$ between 1.2 - 1.4. The present observations suggest an average of 2.4 for $\lambda8542/\lambda8498$ and 1.2 for $\lambda8542/\lambda8662$ for the 17 stars for which $\lambda8662$ has been observed. It is worth the comment here that the ratios $\lambda8542/\lambda8498$ compare rather well among various observations although the individual EQW measures differ quite a bit. It shows an internal consistency within each analysis. For a later comparison with the theoretically predicted EQW of the 2 lines $\lambda8542$ and $\lambda8662$ together, we have estimated the EQW of $\lambda8662$ on the basis of the above average ratios and have shown in Col. 7 of Table 2, the sum of the observed EQW of 8542 Å and the estimated EQW of 8662 Å, designated as 'W' for all the program stars.

3. Ca II triplet strengths as a function of stellar atmospheric parameters

3.1. *Surface gravity*

Figures 1a-e show sample reduced spectra for stars having a range of luminosities for roughly the same spectral type. The five cases shown are for G0-G1, G4-G5, K1, K2 and M0-M4. There exists a definite correlation between the Ca II strength and luminosity. The lines are very strong in supergiants and quite weak in dwarfs. Figure 2a shows the plot of Ca II EQW and log g for the whole sample, i.e., for all metallicities. Although the scatter is large, the EQW of Ca T anticorrelates with log g strongly. As the theoretical computations of Erdelyi-Mendes & Barbuy (1991) and JCJ show, the observed Ca T EQW's increase non-linearly with decrease in log g. Our observations show trends very similar to the theoretical results of JCJ in the sense that there is a strong increase in EQW (from 5.0 to 9.0) for small log g (from 2 to 0) and a modest increase in EQW (from 3.5 to 5.0) for higher log g (from 4 to 2). It is worth noting here that W cited in Table 2 for stars with known log g, $T_{\rm eff}$ and metallicity match rather well with the theoretical EQW ($W_{\rm NLTE}$) of the Ca II lines $\lambda\lambda8542$, 8662 (calculated in NLTE) given in Table 2 of JCJ calculated for the corresponding values of log g, $T_{\rm eff}$ and metallicity. Such a good agreement suggests that the theoretical model of JCJ gives a reasonably good description of the formation of the Ca II infrared triplet lines. We shall soon see that part of the large scatter is a consequence of the chemical inhomogeneity of the sample. In fact, JAJ have shown that the deviations of the observed points from this relationship are correlated with metallicity. Stars with higher metal content have stronger Ca II lines. In Figs. 2b and 2c, we have plotted log g of the subsamples of metal rich and metal poor stars respectively against the Ca II EQW. It is obvious that tight correlation exists between log g and EQW for the metal rich stars. The observational data of JAJ and DTT show a similar relationship between the two. This is also in agreement with the theoretical computations by JCJ. The present observational data show that for [Fe/H] ≥ 0.0, the EQW is about 3 times higher for stars with log $g = 0$ than for those with log $g = 4$. For [Fe/H] < 0.0, the corresponding factor is around 2. The two encircled filled circles belong to the two stars ρ Per (M4 II) and μ Gem (M3 III). They show a large deviation from the strong correlation defined by the rest of the stars. It is highly likely that there are uncertainties involved in the location of the continuum in these two stars because of the appearance of strong TiO bands in them. As a consequence, the measured EQW's might actually have been underestimated. As suggested by DTT, this strong dependence of the Ca II EQW on log g can be exploited to determine the luminosity of stellar systems unambiguously from the observed Ca II triplet strengths provided a good calibration is first established. For the metal poor stars too, we find the correlation but it is not as tight. In fact, DTT found no correlation at all between the Ca II EQW and log g for metal poor stars ([Fe/H] ≤ -0.3) and suggested that since the Ca II triplet has no dependence on gravity for metal poor stars and it is easily measurable in stars with very low metal content, it is a useful metallicity indicator for metal poor stellar systems. This is also possible in the case of globular clusters where the near-infrared light is dominated by stars in a restricted gravity range. Metallicity has been determined for several globular clusters by DTT based upon the calibration established by Armandroff & Zinn (1988). DTT covered a much wider range of metallicity than we have done. We have to include many more metal poor stars (with [Fe/H] down to as low as -2.0) to substantiate the relationship.

3.2. *Effective temperature*

Figures 3a-d show the spectra of stars arranged over a range of spectral types for a given luminosity. The four sets of spectra are shown for luminosity type Ib, II, III, V, each ranging from around G0 to M3. This was done to see if there are any temperature effects. Figure 4 shows the plot between the Ca II EQW and (R-I). It appears more or less like a scatter diagram. We have not yet been able to cover dwarfs and subgiants over a large enough range of (R-I). This explains the lack of points to the lower right of the diagram. For giants and supergiants there is a random spread of EQW over the range of (R-I). This is in contrast to the theoretical calculations of Erdelyi-Mendes & Barbuy (1991) which show that the temperature effects are quite pronounced for log $g < 1.0$ although they are minimal for dwarfs. The theoretical study of JCJ also shows that the EQW's of Ca II are sensitive both to log g

and $T_{\rm eff}$, especially for low metallicity stars. Zhou (1991) has detected for stars with $(R\text{-}I) \geq 1.0$ a trend of EQW's decreasing with increase in $(R\text{-}I)$. It is entirely possible because at very low temperatures ($T_{\rm eff} < 4000$ K), the first ionization of Ca will substantially reduce. However, this systematic trend could also be an observational artifact because of the TiO bands getting stronger for cooler stars, thus resulting in depressing the continuum in the vicinity of the Ca II triplet and a lowering of the Ca II EQW's. JCJ (1992) in their theoretical plots of EQW vs. $T_{\rm eff}$ detected a convex shape in the dependence with log g as a parameter. In Figs. 5a, b and c, we have plotted the Ca II EQW against $\theta_{\rm eff} = 5040/T_{\rm eff}$ for supergiants, giants and dwarfs respectively. There might be a vague suggestion of a convex appearance. However, in view of the limited sample especially of dwarfs that we have here, our observations reveal little dependence on temperature, independent of gravity or metallicity. We thus infer that the Ca II triplet strengths are more of a luminosity indicator than a temperature indicator.

3.3. *Metallicity*

Figure 6a shows how the Ca II triplet strengths are related to [Fe/H], which is usually taken as a measure of metallicity. There is a large scatter primarily because of the strong dependence on luminosity. Supergiants are on top separated from giants below and dwarfs still further down. The dependence of the Ca II triplet fluxes on gravity and metallicity is intricately intertwined as Smith & Drake (1987, 1990) have shown in their LTE calculations. If we plot this relationship only for supergiants, we find as seen in Fig. 6b a distinctly strong relationship between the EQW and [Fe/H]. Once again, the dependence is not linear. Instead it follows an exponential behaviour as shown theoretically by JCJ. In the case of giants and dwarfs, the correlation is much milder. JCJ's computations also show the dependence of the Ca II EQW on metallicity to be much stronger for supergiants than for giants and dwarfs. The metallicity factor [Fe/H] in our sample is restricted between +0.6 and −0.65. It is extremely important to include metal poor stars with [Fe/H] ≤ -1.0 for a more complete analysis of the behaviour of the Ca II triplet EQW with respect to metallicity. Only when a large metallicity range is considered (i.e., $\geq$1.0 dex), the influence of the metallicity on the Ca II triplet lines becomes conspicuous. In the narrower metallicity range, the Ca II triplet EQW displays only its strong dependence on gravity.

The present study tacitly assumes that [Fe/H] directly reflects the abundance of heavy elements in general and of calcium in particular. This is true only if the ratio Ca/Fe is independent of metallicity. From their observations, DTT obtained an analytic relation for the EQW as a function of log g and [Fe/H]. The results of JCJ's analysis which directly employs calcium abundance instead of the customary [Fe/H], together with the DTT relation reveal that Ca/Fe is an increasing function of metallicity. In that case, the interpretation of the relationship between the observed Ca II EQW and [Fe/H] for a given log g is no longer straightforward. A given [Fe/H] implies a higher [Ca/H]. Therefore the observed strength of the Ca II triplet has a contribution from the calcium abundance which is in excess over what is implied by the given metallicity [Fe/H] if Ca/Fe were independent of metallicity. One has to keep this in mind when deriving conclusions from the relationship between the Ca II EQW and [Fe/H] for various log g's.

4. Conclusions

To conclude, our data convincingly show that the Ca II triplet is biparametric with a strong dependence on luminosity and a milder dependence on metallicity. It is extremely important that a large parameter space is spanned among the stars contributing to the integrated light of galaxies. We plan to extend the sample to stars of higher $(R\text{-}I)$, more dwarfs and subgiants and more metal poor stars with [Fe/H] ≤ -0.75. Only with a more complete data, it is possible to substantiate the results more definitely and exploit this information in the studies of the stellar population synthesis of star clusters and nuclei of galaxies as a constraint on the giant: dwarf ratio and/or the metallicity of the systems.

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Table 1. Stellar parameters

	Names		Spectral				
HD	HR	Other	type	θ_{eff}	R-I	log g	[Fe/H]
9826	458	υ And	F8 V	0.84	0.29	3.91	-0.23
10700	509	τ Cet	G8 V	0.96	0.47	4.50	-0.58
12533	603	γ^1 And	K3 IIb	1.15	0.69	0.92	-0.23
16895	799	θ Per	F8 V	0.84	0.30	4.06	-0.15
17506	834	η Per	K3 Ib	1.17	0.89	1.0	-0.15
19058	921	ρ Per	M4 II	1.44	1.62	0.8	+0.05
19373	937	ι Per	G0 V	0.84	0.29	4.0	+0.10
22049	1084	ϵ Eri	K2 V	1.01	0.46	4.80	-0.20
26630	1303	μ Per	G0 Ib	0.92	0.55	1.50	+0.15
26965	1325	o^2 Eri	K1 V	0.99	0.45	4.31	-0.34
29139	1457	α Tau	K5 III	1.31	0.94	1.5	+0.00
29503	1481	53 Eri	K2 IIIb		0.56	2.69	
31398	1577	ι Aur	K3 II		0.82	1.66	+0.00
31421	1580	o^2 Ori	K2 III		0.63	2.69	
31767	1601	π^6 Ori	K2 II		0.70		
32887	1654	ϵ Lep	K5 III		0.81	2.32	
36079	1829	β Lep	G5 II		0.44	2.2	
39425	2040	β Col	K2 III	1.10	0.58	2.80	+0.13
39587	2047	χ^1 Ori	G0 V	0.85	0.31	4.50	-0.05
39801	2061	α Ori	M1 Iab		1.28	0.00	
40035	2077	δ Aur	K0 III		0.52	2.92	+0.02
41116	2134	1 Gem	G7 III		0.45	3.08	
42995	2216	η Gem	M3 III		1.31	1.50	
43232	2227	γ Mon	K3 III		0.64		
44033	2269		K3 Ib	1.53	1.06	1.13	-0.07
44478	2286	μ Gem	M3 IIIab	1.40	1.38	1.08	+0.11
44537	2289	ψ^1 Aur	M0 Iab	1.65	1.07	1.0	+0.08
44762	2296	δ Col	G7 II		0.47	2.2	
48329	2473	ϵ Gem	G8 Ib	1.10	0.61	0.8	-0.05
50310	2553	τ Pup	K1 III		0.60		
50522	2560	15 Lyn	G5 III		0.44		
50778	2574	θ CMa	K4 III	1.27	0.78	1.9	-0.03
50877	2580	o^1 CMa	K2 Iab	1.19	0.82	0.00	-0.11
52005	2615	41 Gem	K3 Ib	1.15	0.85	0.8	-0.21
52877	2646	σ CMa	K7 Iab		1.00	1.0	
52973	2650	ζ Gem	G0 Ib	0.88	0.41	1.63	+0.33
54605	2693	δ CMa	F8 Ia	0.81	0.33	0.6	+0.19
56577	2764		K3 Ib	1.12	0.99	1.35	+0.15
56855	2773	π Pup	K3 Ib		0.91	1.13	
59717	2878	σ Pup	K5 III		0.92		
60522	2905	ν Gem	M0 III		0.91		
62345	2985	κ Gem	G8 IIIa	1.14	0.45		-0.20
62509	2990	β Gem	K0 IIIb	1.05	0.50	2.6	-0.11
62576	2993		K3 Ib	1.17	0.97	1.3	+0.01
63700	3045	ξ Pup	G3 Ib	1.01	0.55	1.15	+0.24
64440	3080		K1 II		0.56	1.6	
71369	3323	o UMa	G5 III	0.97	0.45	2.3	-0.02
74006	3438	β Pyx	G7 Ib		0.48		
74442	3461	δ Cnc	K0 III		0.54		
74874	3482	ϵ Hya	G5 III	1.01	0.39	3.14	
75691	3518	γ Pyx	K3 III		0.68	2.45	
76294	3547	ζ Hya	G9 II	1.13	0.49	2.5	-0.12
78647	3634	λ Vel	K4 Ib	1.19	0.94	1.4	+0.23
81797	3748	α Hya	K3 II	1.15	0.77	1.86	-0.19
84441	3873	ϵ Leo	G1 II	0.93	0.43	2.40	-0.13
89484	4057	γ Leo	K0 III	1.08	0.62	2.39	-0.35
89758	4069	μ UMa	M2 IIIab		0.96	1.35	
92125	4166	37 LMi	G2 II		0.38		
93813	4232	ν Hya	K2 III		0.64	2.69	-0.19
94264	4247	46 LMi	K0 III	1.07	0.54	2.5	-0.22
96833	4335	ψ UMa	K1 III	1.04	0.57	2.78	-0.07
96918	4337		G4 0-Ia	0.88	0.59	0.4	+0.32
97778	4362	72 Leo	M3 II		1.31		
98430	4382	δ Crt	G8 III	1.04	0.60	2.48	-0.33
100407	4450	ξ Hya	G7 III	1.04	0.48	2.2	-0.10
102224	4518	χ UMa	K0 III	1.26	0.60	2.92	-0.65
102870	4540	β Vir	F9 V	0.83	0.28	4.1	+0.18
108903	4763	γ Cru	M3.5 III		1.41		
109379	4786	β Crv	G5 II		0.44	2.2	
112300	4910	δ Vir	M3 III	1.38	1.33	1.3	-0.09
113226	4932	ϵ Vir	G8 IIIb	1.01	0.45	2.7	+0.10
114710	4983	β Com	G0 V	0.85	0.30	4.4	+0.02
117440	5089		G9 Ib	1.29	0.59	1.86	-0.36
121370	5235	η Boo	G0 IV	0.81	0.29	3.8	+0.16
123139	5288	θ Cen	K0 IIIb	1.00	0.53	2.93	+0.04
124897	5340	α Boo	K1 IIIb	1.19	0.65	1.7	-0.60
126868	5409	ϕ Vir	G2 IV		0.37	3.9	
129989	5506	ϵ Boo	K0 II		0.52	2.5	
135722	5681	δ Boo	G8 III	1.05	0.51	2.70	-0.50
140573	5854	α Ser	K2 III	1.1	0.57	2.9	+0.37
148856	6148	β Her	G7 III	1.20	0.48	3.08	+0.18
150680	6212	ζ Her	G0 IV	0.89	0.32	3.8	-0.19
151680	6241	ϵ Sco	K2.5 III	1.12	0.60	2.5	-0.30
157244	6461	β Arae	K3 Ib	1.10	0.53	1.3	+0.50
161797	6623	μ Her	G5 IV	0.93	0.38	4.1	+0.32
186791	7525	γ Aql	K3 II		0.78	2.4	+0.00
200905	8079	ξ Cyg	K4 Ib	1.23	0.92	1.6	-0.01
206778	8308	ϵ Peg	K2 Ib	1.16	0.76	1.0	-0.03
210745	8465	ζ Cep	K1.5 Ib	1.12	0.78	0.75	+0.22
218356	8796	56 Peg	G8 Ib	1.12	0.68	1.40	-0.20
225212	9103	3 Cet	K3 Ib	1.19	0.78	0.80	-0.20

Table 2. Measured line strengths of the Ca II triplet

HR	Star name	EQW(Å) λ8498	λ8542	λ8662	Ca T (Å)	W (Å)
458	υ And	1.14	2.32		3.46	4.25
509	τ Cet	0.97	2.31		3.28	4.23
603	γ^1 And	2.05	3.61		5.66	6.62
799	θ Per	0.82	3.04		3.86	5.57
834	η Per	2.52	4.59	3.96	7.11	8.41
921	ρ Per	1.65	3.47		5.12	6.36
937	ι Per	1.30	3.09		4.39	5.66
1084	ϵ Eri	1.16	2.96		4.12	5.43
1303	μ Per	1.99	4.88		6.87	8.95
1325	o^2 Eri	1.32	3.11		4.43	5.70
1457	α Tau	1.88	4.20		6.08	7.70
1481	53 Eri	1.37	3.38		4.75	6.10
1577	ι Aur	2.24	4.49		6.73	8.23
1580	o^2 Ori	1.30	3.25		4.55	5.96
1601	π^6 Ori	1.87	4.77		6.64	8.74
1654	ϵ Lep	1.94	3.92		5.86	7.19
1829	β Lep	1.50	3.03		4.53	5.55
2040	β Col	1.57	3.46		5.03	6.34
2047	χ^1 Ori	0.90	1.66		2.56	3.04
2061	α Ori	2.32	5.01	4.23	7.33	9.18
2077	δ Aur	1.39	4.01		5.40	7.35
2134	1 Gem	1.43	3.99		5.42	7.31
2216	η Gem	1.85	3.89		5.74	7.13
2227	γ Mon	1.67	3.70		5.37	6.78
2269		1.59	3.40	3.36	4.99	6.23
2286	μ Gem	1.74	3.64		5.38	6.67
2289	ψ^1 Aur	3.18	5.49	4.58	8.67	10.06
2296	δ Col	1.54	3.44		4.98	6.31
2473	ϵ Gem	2.62	4.71	4.02	7.33	8.63
2553	τ Pup	1.45	4.21		5.66	7.72
2560	15 Lyn	1.28	3.28		4.56	6.01
2574	θ CMa	1.49	2.94		4.43	5.39
2580	o^1 CMa	2.24	4.99	4.83	7.23	9.15
2615	41 Gem	2.05	4.66	4.08	6.71	8.54
2646	σ CMa	2.63	4.68	4.22	7.31	8.58
2650	ζ Gem	1.76	4.66		6.42	8.54
2693	δ CMa	2.78	6.35		9.13	11.64
2764		2.19	4.94	3.89	7.13	9.06
2773	π Pup	2.16	4.35	3.94	6.51	7.97
2878	σ Pup	1.74	4.35		6.09	7.97
2905	ν Gem	1.99	4.21		6.20	7.72
2985	κ Gem	1.21	3.08		4.29	5.65
2990	β Gem	1.37	3.53		4.90	6.47
2993		1.87	4.69	3.65	6.56	8.60
3045	ξ Pup	2.59	5.71		8.30	10.47
3080		1.86	4.30		6.16	7.88
3323	o UMa	1.30	3.27		4.57	5.99
3438	β Pyx	1.52	4.12	2.91	5.64	7.55
3461	δ Cnc	1.21	2.93		4.14	5.37
3482	ϵ Hya	1.15	3.04		4.19	5.57
3518	γ Pyx	1.68	4.00		5.68	7.33
3547	ζ Hya	1.61	4.04		5.65	7.41
3634	λ Vel	2.57	5.45	4.50	8.02	9.99
3748	α Hya	1.93	4.81		6.74	8.82
3873	ϵ Leo	1.32	3.87		5.19	7.09
4057	γ Leo	1.41	3.59		5.00	6.58
4069	μ UMa	1.63	4.29		5.92	7.86
4166	37 LMi	1.89	4.85		6.74	8.89
4232	ν Hya	1.32	3.01		4.33	5.52
4247	46 LMi	1.22	3.82		5.04	7.00

HR	Star name	EQW(Å) λ8498	λ8552	λ8662	Ca T (Å)	W (Å)
4335	ψ UMa	1.60	4.01		5.61	7.35
4337		4.29	8.52		12.81	15.62
4362	72 Leo	2.24	4.59		6.83	8.41
4382	δ Crt	1.34	2.48		3.82	4.55
4450	ξ Hya	1.65	3.71		5.36	6.80
4518	χ UMa	0.96	3.74		4.70	6.86
4540	β Vir	1.01	1.88		2.89	3.45
4763	γ Cru	1.73	4.62		6.35	8.47
4786	β Crv	1.40	3.99		5.39	7.31
4910	δ Vir	1.59	3.37		4.96	6.18
4932	ϵ Vir	1.50	3.21		4.71	5.88
4983	β Com	0.90	2.29		3.19	4.20
5089		1.61	4.72	3.13	6.33	8.65
5235	η Boo	1.08	1.97		3.05	3.61
5288	θ Cen	1.24	2.94		4.18	5.39
5340	α Boo	1.37	3.65		5.02	6.69
5409	ϕ Vir	1.06	2.36		3.42	4.33
5506	ϵ Boo	1.82	3.81		5.63	6.98
5681	δ Boo	1.33	2.93		4.26	5.37
5854	α Ser	1.31	3.36		4.67	6.16
6148	β Her	1.36	4.33		5.69	7.94
6212	ζ Her	1.18	2.28		3.46	4.18
6241	ϵ Sco	1.66	4.01		5.67	7.35
6461	β Arae	2.36	5.26	4.00	7.62	9.64
6623	μ Her	1.10	3.48		4.58	6.38
7525	γ Aql	1.85	4.31		6.16	7.90
8079	ξ Cyg	2.52	5.53		8.05	10.14
8308	ϵ Peg	2.37	5.71		8.08	10.47
8465	ζ Cep	2.60	5.17	4.51	7.77	9.48
8796	56 Peg	1.50	3.43	2.85	4.93	6.29
9103	3 Cet	2.11	4.66		6.77	8.54

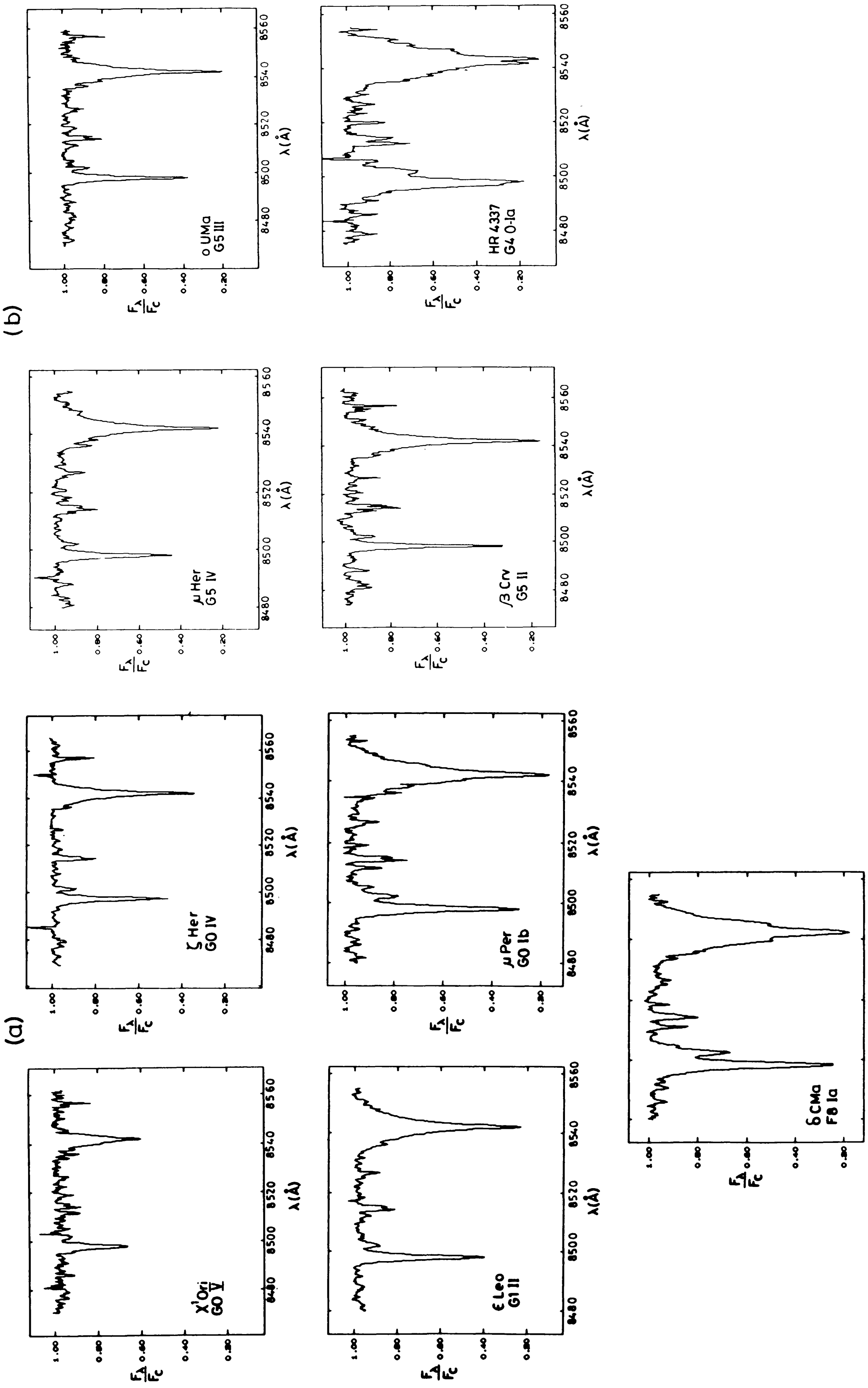

Fig. 1a-e. Representative spectra around Ca II λλ8498, 8542 for stars of each spectral type over a range of luminosities: a) G0-G1, b) G4-G5, c) K1, d) K2, e) M0-M4

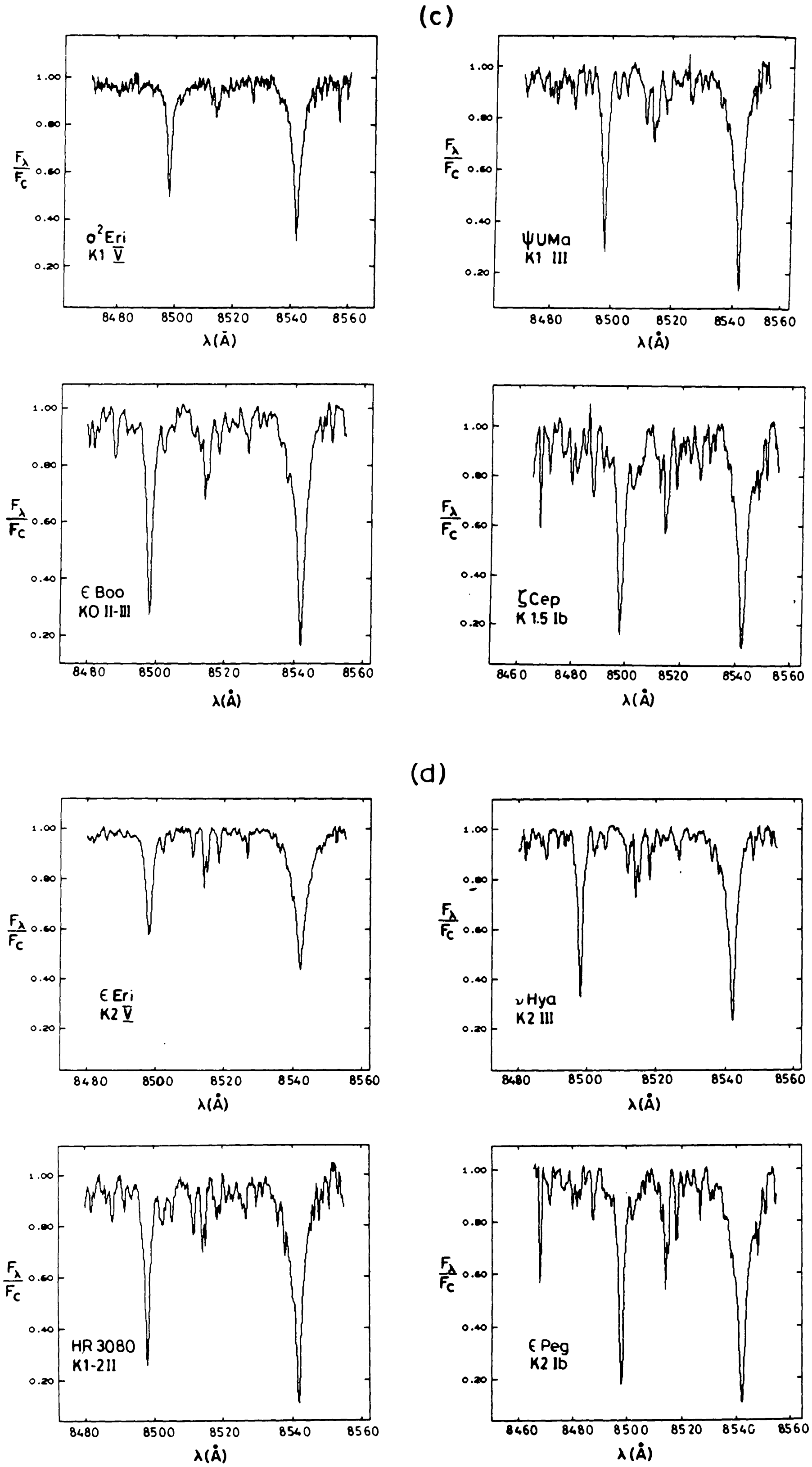

Fig. 1. continued

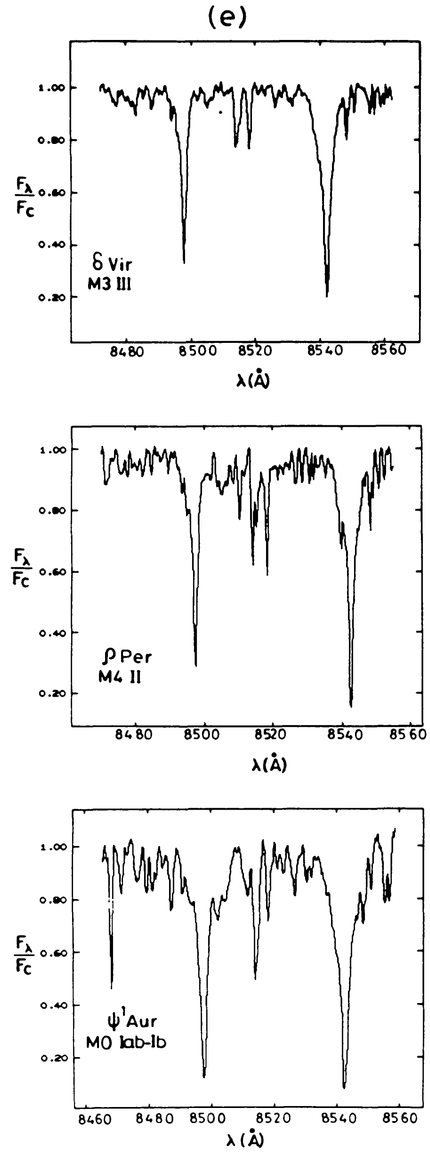

Fig. 1. continued

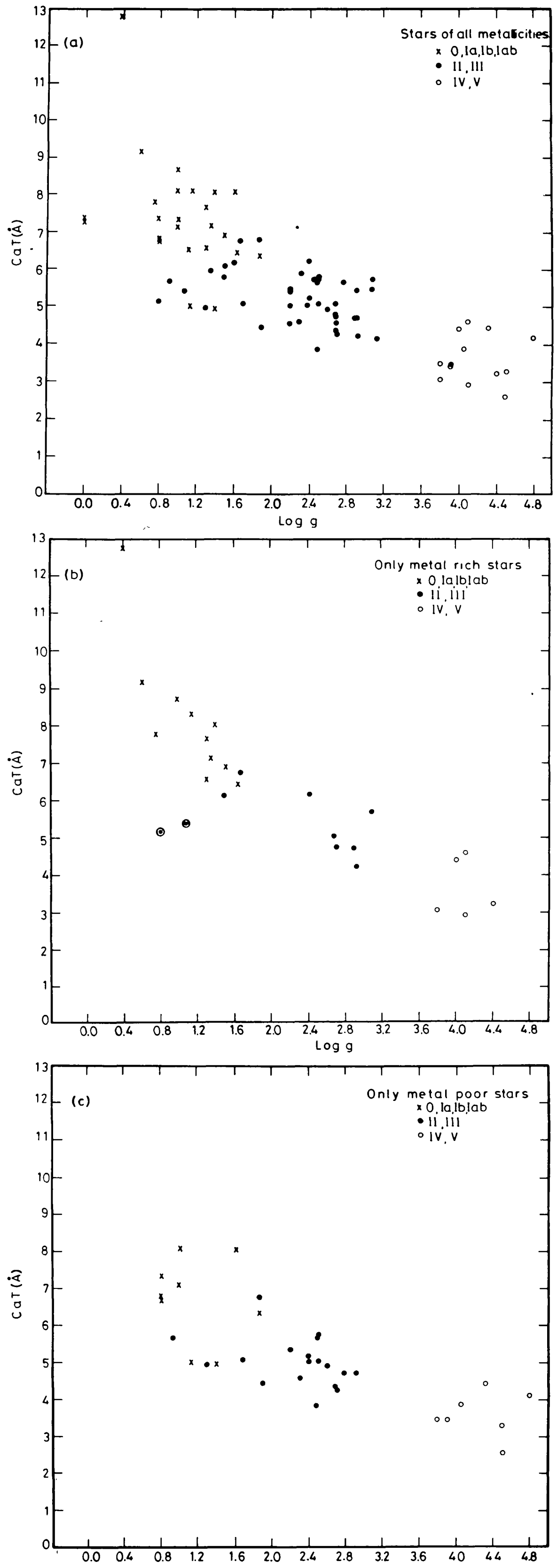

Fig. 2a-c. EQW (Ca T) versus log g : a) for the whole star sample, b) for metal rich stars ([Fe/H]$\geq$0.0), c) for metal poor stars ([Fe/H]$<$0.0). Open circles, filled circles and stars represent dwarfs+ subgiants, giants+bright giants and supergiants respectively. The same holds for the subsequent figs

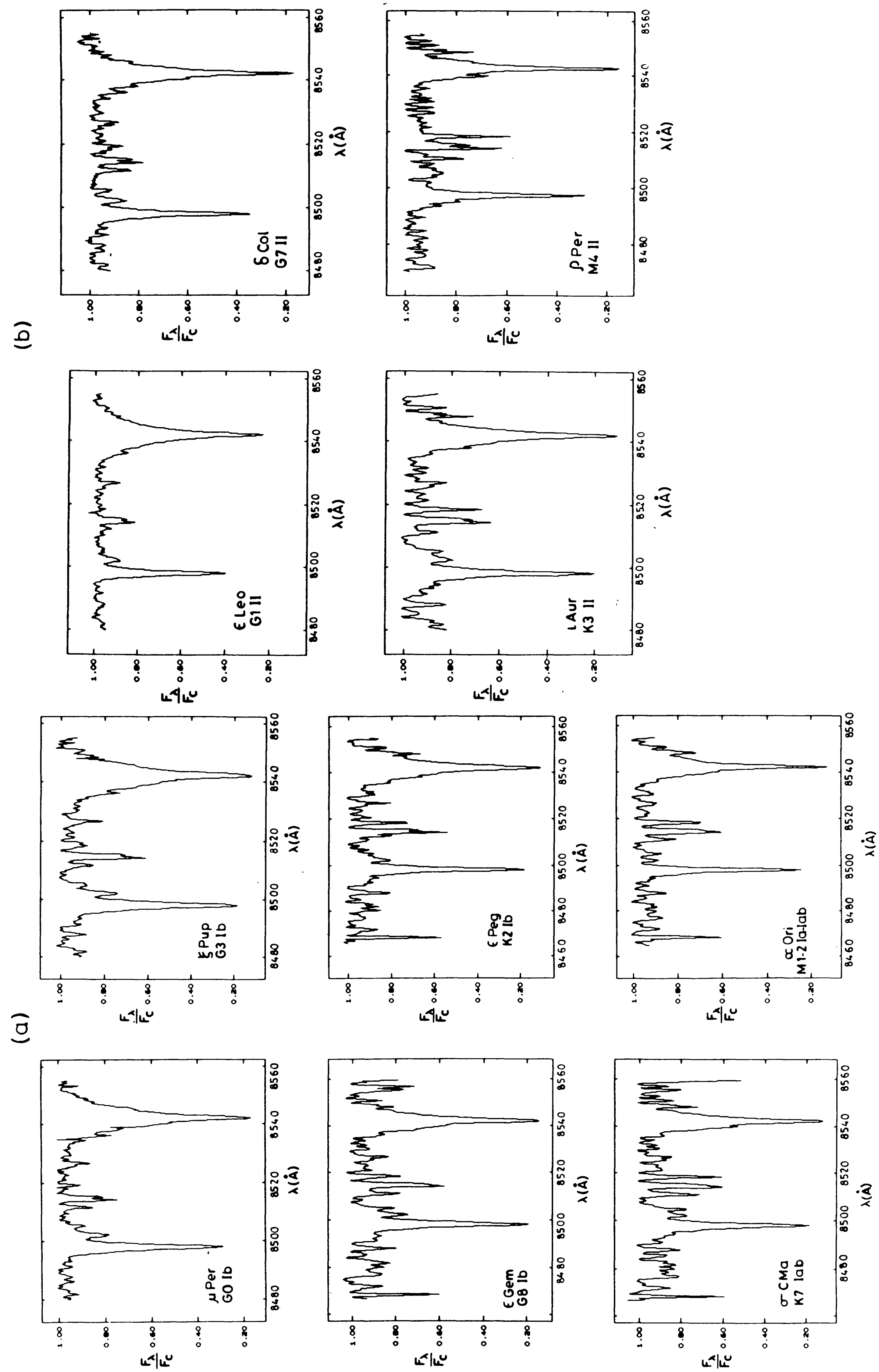

Fig. 3a-d. Representative spectra around Ca II $\lambda\lambda$8498, 8542 for stars of a given luminosity over a range of spectral types: a) Ib, b) II, c) III, d) V

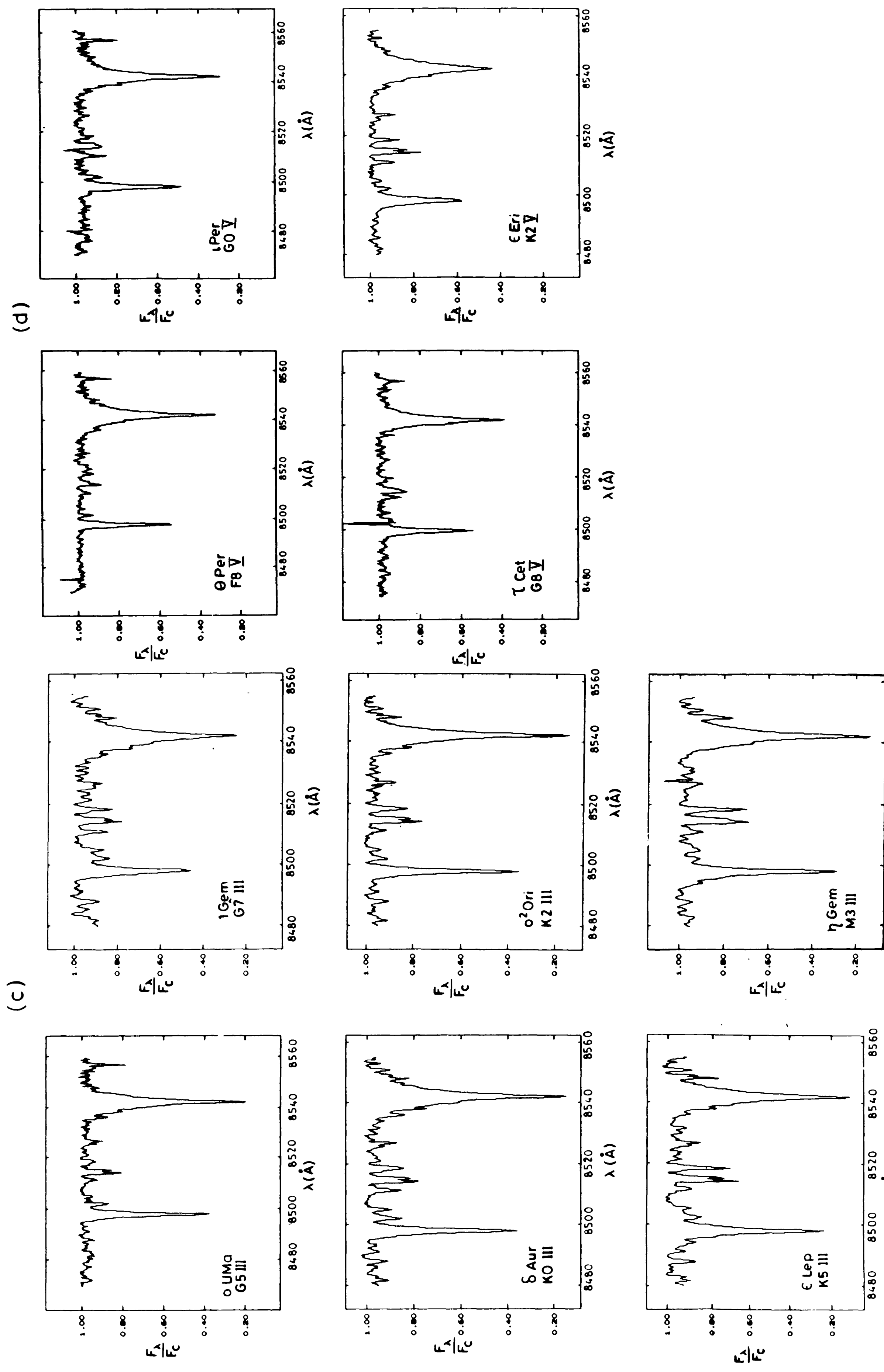

Fig. 3. continued

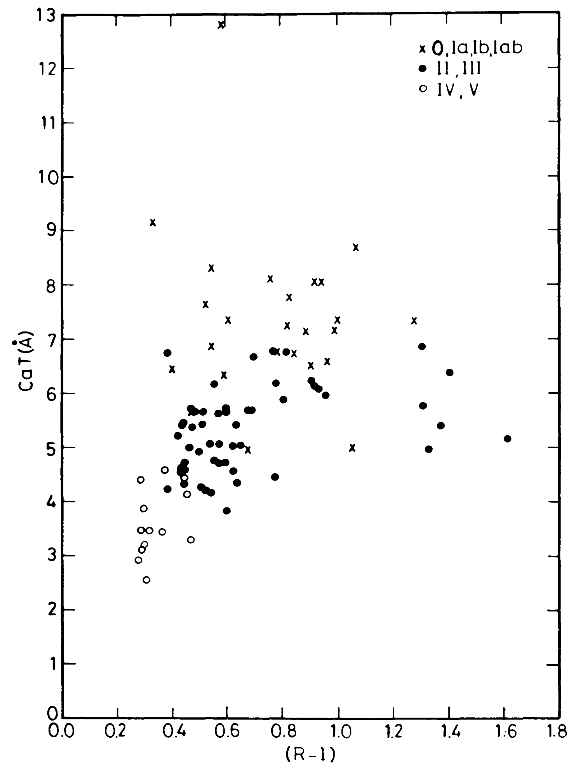

Fig. 4. EQW (Ca T) versus (*R*-*I*)

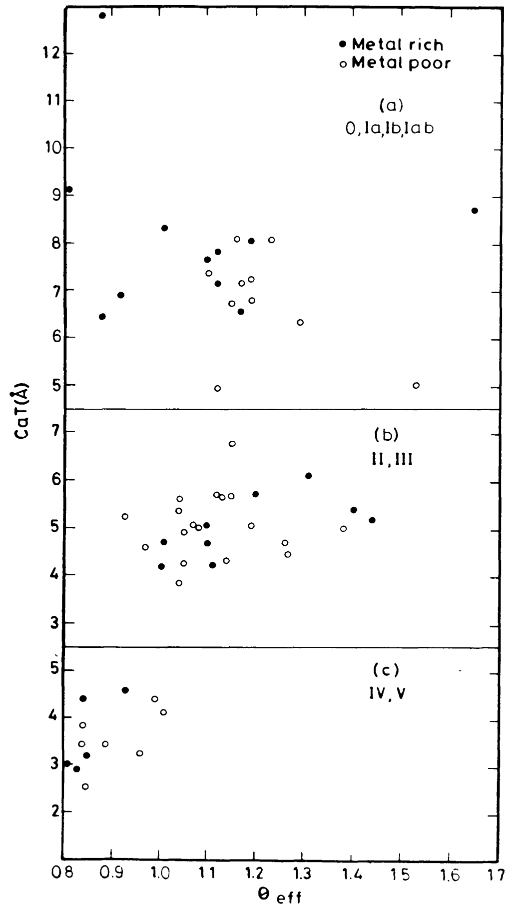

Fig. 5a-c. EQW (Ca T) versus $\theta_{\rm eff}$: a) supergiants, b) bright giants and giants, c) subgiants and dwarfs

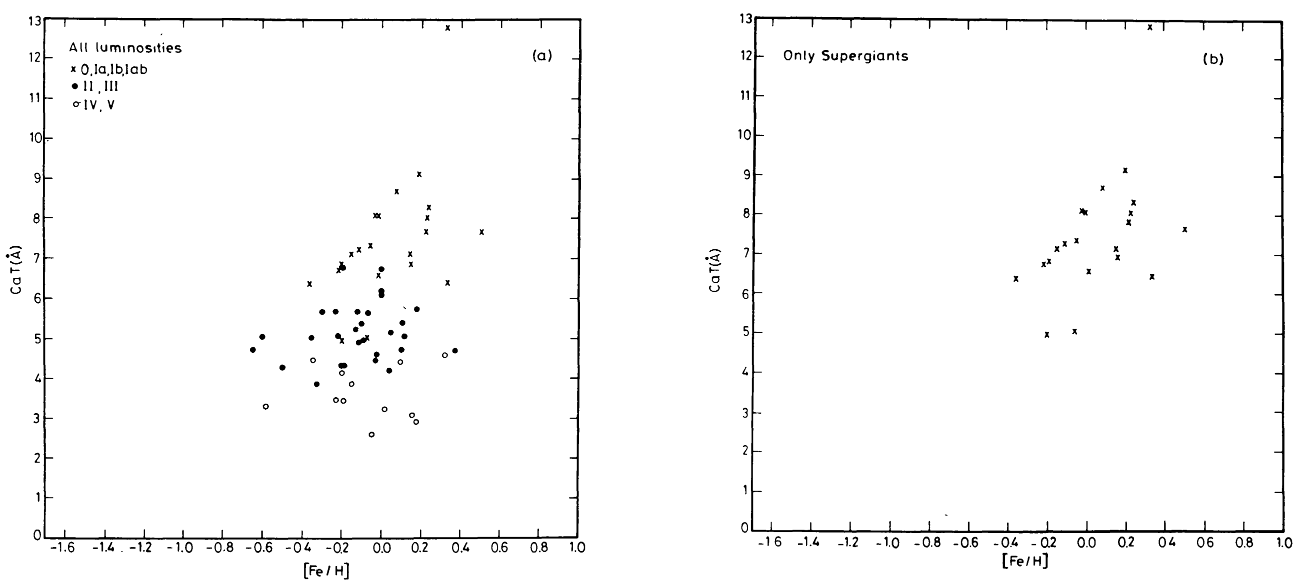

Fig. 6a-b. EQW (Ca T) versus [Fe/H]: a) for the whole sample, b) for supergiants