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Observations of weak G-band stars

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Summary. Scanner observations of the strengths of the G-band of CH at λ4300 and of the NH bands at λ3360 were obtained for 10 weak G-band stars (wG stars) along with 20 normal field giants of spectral types G to K. The differential strengths of these bands in wG stars relative to the field giants show that the weakness of the G-band is linearly related to the enhancement of the NH band strength thus showing that the atmospheric material of the wG stars is processed by the CNO cycle.

Introduction

The spectra of the weak G-band stars (wG stars) are characterized by weak CN bands and G-band of CH for their spectral type, indicating carbon deficiency. A list of 34 stars belonging to this class has been published by Bidelman & MacConnell (1973) from their objective prism surveys. The spectra of 15 of these stars have been classified by Dean, Lee & O'Brien (1977) to be between spectral types G5 to K3 and most of them belong to luminosity class III with a few of luminosity class IV. They also obtained *UBVRI* colours for 24 of these stars. Earlier, Greenstein & Keenan (1958) studied HR 885, the prototype of these objects, and showed that CN and CH are deficient in this star by factors of ~ 30 and ~ 100 respectively. Helfer & Wallerstein (1968) performed a curve of growth analysis for one of these stars, HR 6791, and showed that [Fe/H] is the same for normal population I giants. This conclusion is also supported by the study of the spectrum of HR 6766 by Dean *et al.* (1977). According to the evolutionary models of Iben (1964, 1966) and Sackmann, Smith & Despain (1974); during the cool red-giant stage the surface convection zone penetrates into the interior mixing-out material which was processed via the CNO tri-cycle. If equilibrium is reached for the CNO cycle, 98 per cent of C and O are converted to N, while the sum of the CNO abundances remains constant for $T \lesssim 10^8$ K (Clayton 1968). Thus if carbon is deficient, as in wG stars (the abundance of CH would also depend on the amount of oxygen present), the nitrogen abundance is expected to go up, if the CN cycle is operative and mixing occurs. This investigation is undertaken to test the above possibility by studying the strength of CH($A^2\Delta - X^2\pi$(0, 0) and (1, 1) bands at λ4300) and NH($A^3\pi - X^3\Sigma^-$(0, 0) and (1, 1) bands at λ3360), which reflect the abundances of carbon and nitrogen in wG stars.

Observations and results

The observations were done with the photoelectric spectrum scanner (Bappu 1977) attached to the Cassegrain focus of the 40-inch telescope at Kavalur. The optical system of the scanner is of the Ebert–Fastie type consisting of a spherical mirror of 1-m radius and a 600 line/mm grating blazed at 7500 Å in the first order which gives a dispersion of 12.5 Å/mm in the second order at the exit slot. The system is used with an EMI 9804 photomultiplier and a BG 12 filter. The spectral scans were obtained with a 25-Å exit slot and cover the wavelength regions λλ3250–3450, λλ4035–4075, λλ4200–4380 and λλ4490–4510, with successive wavelength steps separated by 5 Å. After correcting for atmospheric extinction, indices (I) which show the band strength are formed as a ratio of the counts in the feature to the counts in the continuum at the feature. Two continuum points (C_1, C_2) are taken at roughly 50 Å from the feature on either side. For the NH bands, the counts in the feature are taken as the average of counts at λλ3360, 3365 and 3370. The counts for the continuum points are taken as the average counts at λλ3310, 3315 (C_1) and at λλ3415, 3420 (C_2). The continuum count at the feature wavelength is obtained by interpolation between C_1 and C_2. Similarly, for the CH bands, the counts in the feature are taken as the average of counts at λλ4295, 4300 and 4305 and the counts for the continuum points are taken as the averages of counts at λλ4245, 4250 and 4255 (C_1) and λλ4345, 4350 and 4355 (C_2). These band strength indices I_{CH} and I_{NH} not only reflect the absorption of the molecular bands but also include some other atomic lines occurring in the 25 Å bandwidth centred near the feature. Because of the similarities between the spectra of wG stars and those of normal field giants of the same spectral type, except for the molecular band strengths (Helfer & Wallerstein 1968; Greenstein & Keenan 1958), differences in I_{CH} and I_{NH} between normal and wG giants are indicative of differences between the molecular band strengths.

To make a differential study of these band indices with respect to field giants, 20 giants of population I between spectral types G3 and K4 were observed along with 10 wG stars. Table 1 gives the observed indices for normal giants and Table 2 gives some relevant data on colours and the indices for wG stars along with the CH band index measured by Spinrad & Taylor (1969). To see the variation of these indices with effective temperature, the $R–I$ colour, which is a good indicator of effective temperature (Bell 1970), is used. For wG stars, for which observed $R–I$ colours are not available, the following method is used. It is found that the slope of the continuum between λ4250 and λ4360 on the instrumental system is well correlated with $R–I$ colour. Fig. 1 shows the slope index TI, which is the ratio of the difference of counts at λ4250 and λ4360 to the counts at λ4360 multiplied by 100, plotted against the observed $R–I$ colour. The mean deviation of TI in Fig. 1 is about 2.2 which corresponds to an uncertainty in the $R–I$ colour of about ± 0.028.

In Fig. 2 the band indices I_{NH} and I_{CH} are plotted against the $R–I$ colour both for normal field giants (dots) and for wG stars (open circles). The mean line drawn is taken to be the variation of the band strength with the $R–I$ index for normal giants. The figure clearly shows that wG stars have their NH bands enhanced. The deviations of the I_{CH} index from the mean line for the 10 wG stars are plotted against the corresponding deviations for I_{NH} in Fig. 3, which shows a linear increase of the NH band strength with CH band deficiency, confirming the expectation. Moreover, the slope of the line seems to be unity which, in turn, indicates an exact balancing between the deficiency of CH and the enhancement of NH. Tusji's (1964) calculations of molecular equilibria with different CN abundances, for log $Pg \lesssim 3$ and temperatures of 4200–5010 K (probably corresponding to the molecule-forming regions in these stars), indicate that the changes in total abundance of carbon and nitrogen are almost directly proportional to changes in the molecular abundances

Table 1. Field giants.

Star	Spectral type	$R-I$	I_{CH}	I_{NH}	CH (ST)	Star	Spectral type	$R-I$	I_{CH}	I_{NH}	CH (ST)
37LMi	G3 II	0.38	0.941	0.915		ϵ And	G8 III	0.51	0.880	0.905	
o UMa	G5 III	0.42	0.907	0.902		β For	G6 III	0.54	0.882	0.894	
HR 1327	G5 III	0.43	0.930	0.906		33 Psc	K1 III	0.54	0.866	0.902	0.38
5 CVn	G7 III	0.44	0.911	0.916		ω Per	K0 III	0.57	0.885	0.896	0.34
o Tau	G8 III	0.45	0.902	0.890		χ Gem	K2 III	0.585	0.865	0.905	0.35
κ Gem	G8 III	0.45	0.899	0.911	0.34	ρ Ori	K3 III	0.59	0.891	0.889	
τ Cnc	G8 III	0.454	0.885	0.890		30 Gem	K1 III	0.60	0.886	0.880	0.32
56 UMa	G8 II	0.46	0.890	0.902		τ Gem	K2 III	0.63	0.889	0.897	0.32
32 And	G8 III	0.46	0.904	0.897		HR 3145	K2 III	0.67	0.873	0.910	0.34
υ^2 Cas	G8 III–IV	0.50	0.904	0.905		β Cnc	K4 III	0.78	0.878	0.894	0.31

Table 2*. wG stars.

HD number	Spectral type	$U-B$	$B-V$	$R-I$†	V	I_{CH}	I_{NH}	CH (ST)	I_{CH}	I_{NH}
18474‡	G4 III	0.61	0.89	(0.43)	5.47	0.968	0.852		−0.052	+0.056
18636				(0.50)	7.6	0.926	0.862		−0.036	+0.040
21018		0.51	0.86	(0.40)	6.37	0.936	0.903		−0.006	+0.009
26575	G8 III–II	0.96	0.98	0.56	6.44	0.893	0.881		−0.017	+0.017
28932				(0.54)	8.6	0.888	0.910		−0.005	−0.008
31274	K1 III	0.78	0.96	0.52	7.13	0.923	0.877		−0.038	+0.027
40402	G5 III	0.66	0.93	0.52	8.61	0.926	0.865		−0.041	+0.037
91805	G8 III	0.71	0.94	(0.495)	6.10	0.927	0.878		−0.032	+0.026
165634	(G9 III)	0.75	0.96	0.52	4.57	0.965	0.825		−0,080	+0.075
166208	G8 III	0.70	0.91	0.472	4.99	0.944	0.840	0.18	−0.046	+0.062

*Spectral types and colours are from Dean *et al.* (1977) or Johnson *et al.* (1966).
† $R-I$ colours in parentheses are obtained from the method mentioned in the text.
‡ Spectral types from Greenstein & Keenan (1958) and *UBV* colours from Blanco *et al.* (1970).

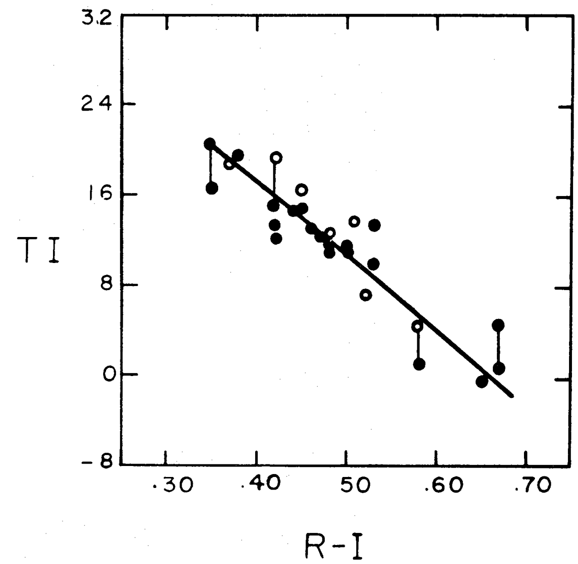

Figure 1. The temperature index TI defined in the text plotted against $R-I$ colour. The circles and dots refer to different nights. Observations of the same star on different time are joined by a vertical line.

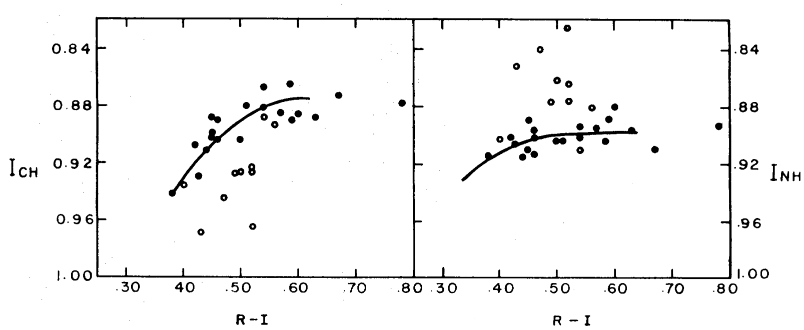

Figure 2. I_{CH} and I_{NH}, the CH and NH band strength indices, plotted against the $R-I$ colour for normal field giants (dots) and wG stars (open circles).

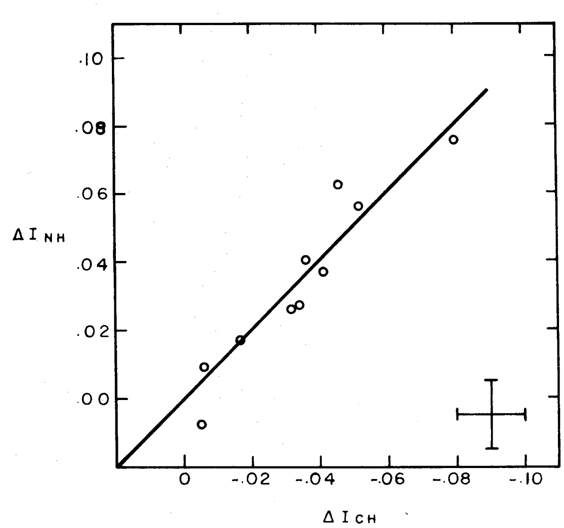

Figure 3. The deviations of I_{CH} plotted against the deviations of I_{NH} for the wG stars.

of CH and NH respectively. Thus the above linearity observed between the deficiency of CH and enhancement of NH band strengths might really reflect the changes in the total carbon and nitrogen abundance and thus confirm that the material in the atmospheres of wG stars is processed by CN cycles. However, because of complications due to saturation effects for the bands, and also since the oxygen abundance is not known, detailed calculations of band strengths are needed before the band-strength parameters can be converted to absolute abundances.

The deficiency of CH and enhancement of NH are relative to the strengths of these bands in the normal field population I giant stars. It would be of interest to see what are the masses of the wG stars and at what stage of evolution this enhanced mixing occurs. These stars could be the counterparts in population I of the asymptotic giant branch stars in the globular cluster M92 (Butler, Carbon & Kraft 1975). The observations of the CH band strength in cluster giants by Spinrad & Taylor (1969) revealed no CH-poor star in the clusters older than the Hyades. This probably suggests a lower limit to the mass and an upper one to the age of the wG stars. An observational programme to search for CH-poor stars among giant stars in clusters is planned.

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