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TiO CONTINUUM PLACEMENT EFFECTS IN 47 TUCANAE GIANTS

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ABSTRACT

High-resolution echelle SIT Vidicon spectra have been obtained of giants in the metal-rich globular cluster 47 Tuc. The sample includes the giants previously investigated with the echelle photographically by Pilachowski, Canterna, and Wallerstein and Cottrell and Da Costa, who derived controversially low abundances. The new spectra show that all of these giants have TiO absorption present in the wavelength region of the previous studies, particularly the two very cool giants in the Pilachowski *et al.* sample. The TiO bands were not recognized in the photographic spectra because they extend over several orders, each of which was analyzed independently. The presence of TiO absorption indicates that the abundances derived by these previous investigations are underestimates because of the underestimation of the continuum. The underestimates are not large, however, amounting to 0.2 dex or less, but this is sufficient to bring the echelle abundances into good agreement with estimates based on recent lower resolution techniques. An abundance for 47 Tuc of [Fe/H] ≈ −0.9, intermediate between the old and new scales, is indicated.

Subject headings: clusters: globular — stars: abundances

I. INTRODUCTION

Despite five years of intensive investigation, the controversy surrounding the absolute, and even relative, abundances of metal-rich Galactic globular clusters continues. A general consensus has developed recently to adopt a "compromise" solution, falling roughly midway between the classical low-resolution scale ([Fe/H] ≈ −0.5 for 47 Tuc) and the new echelle scale ([Fe/H] ≈ −1.1). Although a growing body of evidence supports an intermediate metallicity ([Fe/H] ≈ −0.8) for the prototypical metal-rich clusters 47 Tuc and M71 (e.g., Dickens, Bell, and Gustaffson 1979, hereafter DBG; Cohen 1983; Bessell 1983; Geisler 1984; D'Odorico, Gratton, and Ponz 1985), one cannot easily dismiss previous abundance derivations, whether high or low. A variety of criticisms and solutions have been raised to account for the general discrepancy between high- and low-resolution techniques. Cohen (1983) and Bessell (1983), among others, have suggested that continuum placement in the echelle spectra is at fault. However, very little direct evidence has been found for such an effect, and, indeed, many investigations have shown that echelle equivalent widths do not vary systematically from those obtained from conventional coudé spectra (e.g., Pilachowski *et al.* 1982). Peterson (1981) and Geisler (1984), on the other hand, argue that a substantial enhancement in the light elements Mg and Si can lead to a high overall metallicity in a cool giant, despite its low Fe abundance.

In their pioneering study of 47 Tuc giants at high resolution, Pilachowski, Canterna, and Wallerstein (1980, hereafter PCW) derived [Fe/H] = −1.2 from photographic echelle spectra of two stars. This result, together with the similarly low abundance reported by Cohen (1980) for M71, initiated the current abundance scale controversy. Cottrell and Da Costa (1981, hereafter CD) obtained photographic echelle spectra of four additional giants in 47 Tuc which confirmed the low Fe abundance. This *Letter* reports on new SIT Vidicon echelle spectra of four of the six giants studied by PCW and CD. These spectra all show TiO absorption in the same wavelength region as the previous studies, particularly the two very cool giants that PCW observed. The TiO absorption was not recognized previously. Failure to account for its presence leads to an erroneously low continuum placement and a subsequent underestimation of the abundances derived from absorption lines in the affected regions.

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II. OBSERVATIONS AND REDUCTIONS

The data were obtained in 1984 October with the CTIO 4 m echelle spectrograph. The 31.6 line mm^{-1} echelle grating, 226-1 cross disperser, and the long-focus camera were employed. The 40 mm Big Blue SIT Vidicon was used as the detector. This instrument-detector combination yielded complete spectral coverage from ~ 5400–6600 Å, at a resolution of ~ 0.25 Å. The sample consisted of the two giants in the PCW study (Lee 1977, designation 2620 and 4715) and one CN−strong/CN−weak pair from CD (Lee stars 3501 and 4418). The individual orders were extracted using TVRED software, wavelength- and flux-calibrated via observations of a Th-Ar comparison lamp and flux standards, and then co-added to produce a single ~ 1200 Å–long spectrum.

III. RESULTS AND DISCUSSION

Figure 1 displays the spectrum of star 4715, one of the stars observed by PCW. There are two salient features. First, a forest of strong lines is present. Second, there are four regions

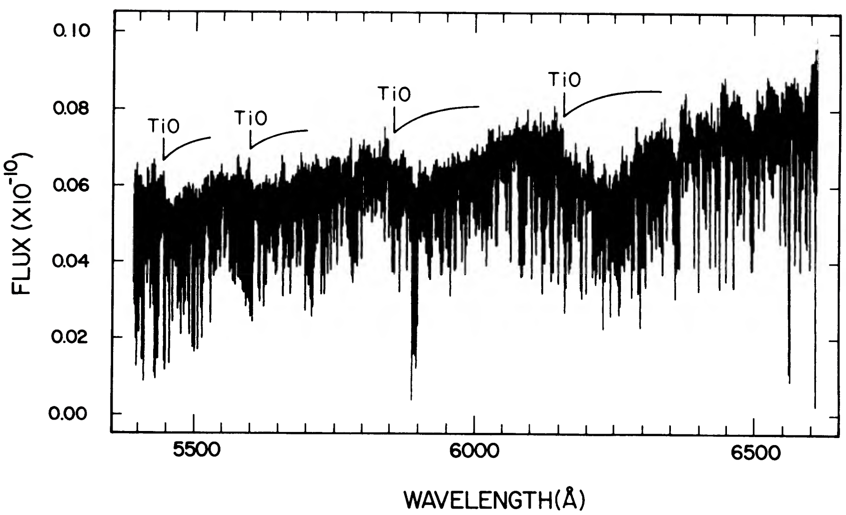

FIG. 1.—Echelle spectrum of star 4715. Four TiO absorption bands are visible.

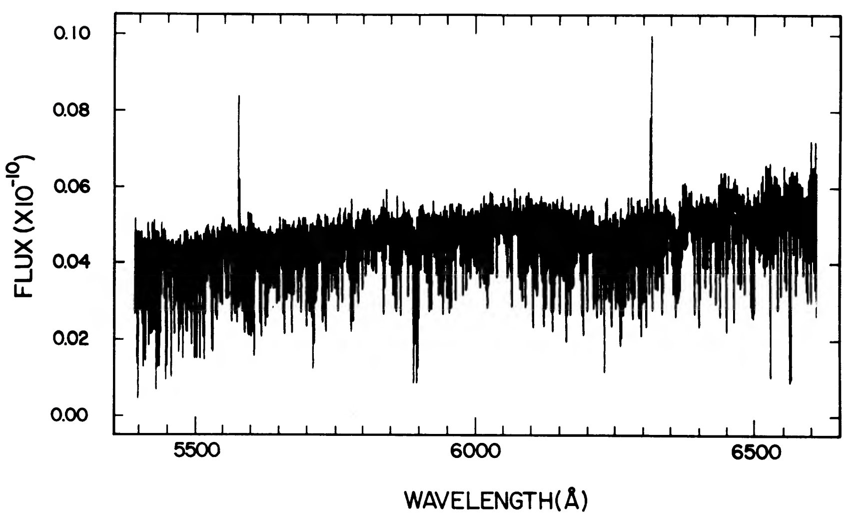

FIG. 2.—Echelle spectrum of star 4418. Although weaker than in star 4715, TiO absorption is still evident, especially in the band near 6250 Å.

of broad depression in the "continuum" level, each covering 100–200 Å. These depressions are all due to TiO bands of the α and β systems, with band heads at 5448, 5598, 5862, and 6159 Å, respectively. The other PCW star, Lee 2620, has TiO absorption virtually as strong as that in 4715. Figure 2 shows the spectrum of star 4418, one of the CD stars. This star is somewhat hotter than 4715, as demonstrated by the bluer continuum and generally weaker lines. However, although TiO absorption is greatly reduced, the bands are still visible, particularly the strongest band centered near 6250 Å. The other CD star, Lee 3501, has a very similar temperature and spectrum.

Feast and Thackeray (1960) first noted the presence of TiO absorption in cool 47 Tuc giants. This has been taken to indicate the Population I–like composition of the cluster. Lloyd-Evans (1983) measured the strength of the TiO bands in stars 2620 and 4715 from $\sim$ 50 Å mm^{-1} spectra in the red. However, several other previous investigations have failed to detect TiO absorption in the stars in the present sample. Feast and Thackeray, in fact, took medium resolution spectra of star 4715 in the blue, but classified it as K0 III, indicating no TiO was visible. DBG obtained 50 Å mm^{-1} spectra in the blue of star 4715 and also did not observe TiO bands. Mould and Bessell (1982) carried out narrow-band photometry of the TiO band near 7120 Å. Their sample included star 3501, for which they found little or no evidence for TiO absorption. Neither PCW nor CD noted the presence of TiO in any of their spectra. However, C. Pilachowski (private communication) states that TiO was seen at wavelengths longward of the limit of their tracings, but that they did not recognize it within the region they measured, where the TiO absorption is somewhat weaker. Indeed, subsequent reexamination of the original PCW plates clearly shows the two strongest bands near 6000 Å as faint continuum weakening.

The failure of Feast and Thackeray (1960) and DBG to detect TiO in star 4715 is most likely due to observations in the blue at low resolution. At a given effective temperature, the TiO bands in the blue (< 5000 Å) are much weaker than those in the red (e.g., Pritchet and van den Bergh 1977). The amount of TiO absorption in star 3501 is small and not in serious conflict with the results of Mould and Bessell (1982). The presence of TiO in stars 3501 and 4418 shows that the onset of TiO absorption occurs in 47 Tuc giants as blue as $B - V = 1.46$, 0.1 mag bluer than the limit found by DBG.

The failure of PCW and CD to detect TiO is undoubtedly a result of using photographic plates with the echelle. A single order on a photographic echellogram obtained with the Singer camera provides useful coverage of only ~ 50 Å. Each order must necessarily be reduced independently, since there is no way to properly flux-calibrate the spectrum. Therefore, photographic echellograms are insensitive to large-scale features, i.e., features broader than one order. The TiO bands that fall in the region of the PCW and CD spectra, however, extend over 150–200 Å. They only become easily visible when one is able to flux calibrate each order and then tie the orders together to form a single spectrum, which is only possible with digital data. It is worth noting, however, that CCD echelle spectra of a single order or CCD coudé spectra of a narrow wavelength region can fall victim to the same effect as the photographic echelle spectra.

What effect does the presence of TiO absorption in the spectrum have on the determination of abundances? First note that the TiO bands fall in the same wavelength region as the PCW and CD spectra. The dissociation energy of the TiO molecule is 6.8 eV, while the ionization potential of Fe I is 7.8 eV. Most of the Fe I lines measured by PCW (given in Pilachowski, Sneden, and Wallerstein 1983, hereafter PSW) have high excitation energies (3–5 eV). The results of a detailed molecular equilibrium and curve of growth analysis using the PSW model atmosphere parameters for star 2620 confirm that TiO is concentrated in layers which overlap with, or are higher than, the regions where typical Fe I absorption lines form. Thus, the continuum for Fe I and similar lines in the regions of TiO bands is significantly higher than the "local" continuum one would draw if the TiO absorption was not accounted for. In the latter case, one would underestimate the continuum level, underestimate the equivalent widths, and underestimate the abundance.

This evidence corroborates the suggestion by Cohen (1983) and Bessell (1983) that errors in the continuum placement in echelle spectra may account for the low abundances derived in some studies of metal-rich globular cluster giants. However, the fault lies not with some subtle effect in the echelle itself but is simply due to the inability to recognize broad spectral features on photographic echellograms. When observing cool, metal-rich stars at high resolution one should employ a system which will allow a flux-calibrated spectrum of at least several 100 Å. It is best, however, to observe stars which are hot enough that T I does not form. The atmospheres of warmer stars are also better understood, and the spectra are less crowded. For cluster giants, this of course means that the hotter stars are also fainter. The advent of very high quantum efficiency CCD detectors makes this possibility feasible. In this regard, we note the work of D'Odorico, Gratton, and Ponz (1985), who have observed a 47 Tuc giant at $V = 13.5$ and $T_{\rm eff} = 4500$ K with a CCD on the ESO 3.6 m echelle. They derive $[\rm Fe/H] = -0.8$, a value very similar to that derived from most recent low-resolution techniques.

We conclude that the Fe (and similar) abundances derived by PCW ($[\rm Fe/H] = -1.2$, whose data was subsequently reanalyzed by PSW and yielded -1.1) and CD (-1.0) are underestimates because of their underestimation of the continuum. It is more difficult to quantify their error. A correct placement of the continuum in the regions of the TiO bands would be difficult and is not attempted here. It is probably significant that the CD abundance is somewhat higher than that of PCW since TiO is much weaker in their hotter stars. The similarity of the PCW and CD abundances, despite the large difference in TiO absorption, is most likely due to the fact that most of the lines analyzed were in uncontaminated regions. The equivalent widths published by PSW allow one to compare the abundances derived from lines in the TiO–affected regions with those in relatively clean areas. We have computed abundances using the same data, parameters, and programs as that employed by PSW for star 2620. Defining the regions of greatest TiO contamination to be 5862–5950 Å and 6159–6350 Å, we find the Fe abundance determined from lines in these regions to be 0.15–0.4 dex lower than that determined from uncontaminated lines, depending on the equivalent-width limits placed on usable lines. However, since the majority of the lines are in uncontaminated regions, the PSW Fe abundance is probably not in error by more than 0.2 dex. The effect is undoubtedly less for the CD stars, although the equivalent width data are not available.

This evidence suggests, then, that the Fe abundance of 47 Tuc is about -0.9. A very similar value (-0.85) is also derived by Geisler (1986) using the Washington photometry of PCW but also a much improved calibration of the Washington abundance indices. This abundance for 47 Tuc, although still somewhat lower than most recent low-resolution values, is now in reasonable agreement with them. The difference of 0.1–0.2 dex is within the uncertainties of the various techniques. The remaining discrepancy may have another explanation. Geisler (1984) has shown that Mg and Si abundances can be significantly enhanced over Fe in metal-rich globulars, leading to a higher overall metallicity and better agreement with low-resolution metallicity estimates. The data of D'Odorico, Gratton, and Ponz (1985) and my reanalysis of PSW data for star 2620 show that Si is strongly enhanced over Fe in these stars. High-dispersion spectra of warm giants which include Mg and Si, as well as Fe, lines may well lead to a resolution of the metal-rich globular cluster abundance scale controversy.

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