THE TEMPERATURES OF G AND K STARS

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ABSTRACT. Effective temperatures have been determined for G and K stars by comparing synthetic colors computed from model atmospheres to observed colors measured at near-infrared continuum points. Results are presented for giant stars in the range K0 III - K4 III.

Effective temperatures of cool stars can be derived from interferometric or occultation measurements of angular diameter, or from calibrations based on model atmospheres. Although the "direct" methods based on angular diameters avoid the many assumptions that must be made in constructing a model atmosphere, the available measurements of angular diameters are in such short supply for certain classes of stars that the model-atmosphere results are more reliable. This is, at present, the case for the G and K stars.

The atmospheres of dwarf and giant stars of types G and K, with temperatures in the range 4000 - 6000 K, can be well represented by atmospheric models (Gustafsson *et al.* 1975; Bell *et al.* 1976). The spectrum emitted by a model can be computed in detail and combined with filter response functions to obtain synthetic color indices (Bell and Gustafsson 1978; Gustafsson and Bell 1979). Color indices computed from a sequence of models of specified T_{eff} then allow the effective temperature to be found for stars with observed color indices. Any well-calibrated photometric system which provides a temperature-sensitive color index can be used in this manner, but the accuracy of the temperatures derived depends upon the ability of the color index to discriminate against the effects of all parameters other than temperature (e.g. composition, gravity, and microturbulence) as well as upon the ability of the model to represent the actual atmosphere of the star.

The eight-color system of narrow-band photometry described by Wing (1971) is particularly well suited for temperature determinations in G

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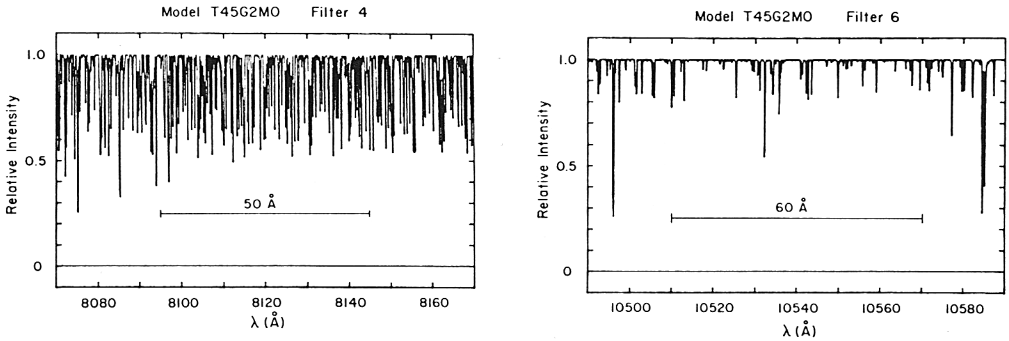

Fig. 1. Synthetic spectra in the regions of two filters of the eight-color system (half-power points indicated) for a solar-composition, 4500 K giant. Filter 4 (*left*) is strongly affected by CN, while filter 6 (*right*) is an excellent continuum point.

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and K stars. Its filters lie in the 7000 - 11000 Å region where atomic lines are very weak, so that effects caused by atomic line absorption are minimal and the incompleteness of atomic line lists is not an important problem. In G and early K stars, the only significant absorber within the eight-color filter bandpasses is the CN molecule, the spectrum of which is well known. The system includes continuum points centered at 7810 Å (FWHM = 40 Å) and 10540 Å (FWHM = 60 Å), which are only slightly affected by CN, as well as filters located within strong CN bands. The system has been calibrated absolutely by fitting the photometry of Vega (A0 V) to a 9500 K model. Although there remains some uncertainty in the temperature of Vega, an error of 100 K in this choice introduces an error of only 25 K in the derived temperatures of K stars.

In Figure 1, two examples of synthetic spectrum calculations are shown. On the left is the region of filter 4 (8120 Å, FWHM = 50 Å), which is strongly affected by CN lines from the (3,1) and (2,0) bands. On the right is the region of filter 6, one of our continuum points.

We have computed synthetic eight-color photometry for most of the solar-composition models published by Bell *et al.* (1976) and for a number of additional models computed by the same procedures subsequently. The model temperatures range from 3500 to 5780 K and the gravities from log g = 0.75 to 4.5 (cgs units). A two-dimensional grid is needed to determine whether the same calibration of color index into T_{eff} can be used at all luminosities. We also considered several metal-deficient models to verify that our continuum points are immune to metallicity effects. To explore the effects of CN we constructed new models with altered nitrogen abundance, and we also computed spectra with the oscillator strength of the CN red system arbitrarily raised or lowered.

Synthetic eight-color photometry for a 5000 K giant and a 4500 K supergiant are shown in Figure 2 with their model continua. Most of the absorption in all filters in due to CN. The model continua are flatter than blackbody curves because H^- continuous opacity depresses the 8000 Å region more than the one-micron region. At the bottom of Figure 2 is

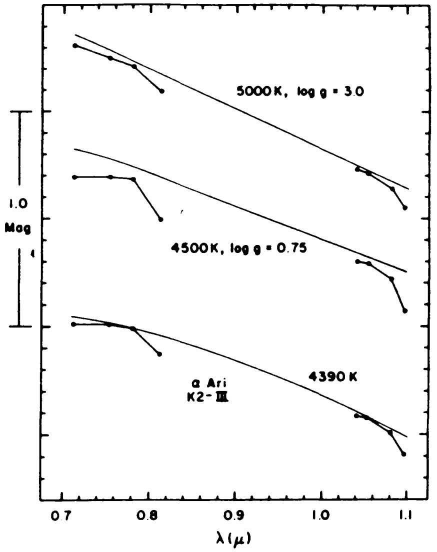

Fig. 2. Eight-color spectra of two models and the star α Ari.

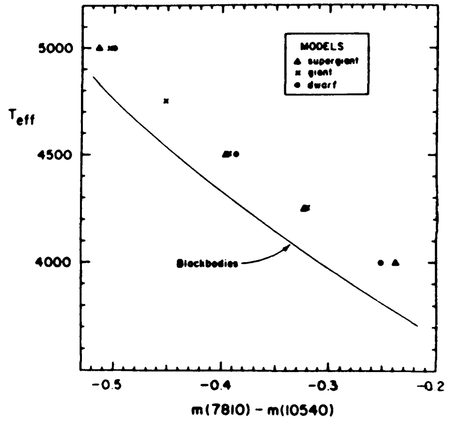

Fig. 3. Synthetic continuum colors *vs.* effective temperature. Opacity from H^- makes all models redder than blackbodies.

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plotted the photometry of the standard star α Ari ($K2^-$ III), fitted with a blackbody curve for 4390 K which passes through the continuum points at 7810 and 10540 Å. Thus 4390 K is the *color* temperature of α Ari on the eight-color system; its *effective* temperature — i.e. the effective temperature of the model which has the same value of the color index m(7810) - m(10540), as well as similar values of gravity, microturbulence and CN strength — is about 200 K higher.

In Figure 3, the computed m(7810) - m(10540) colors are plotted against the effective temperatures of the models from which they were derived. All models are redder, in this index, than blackbodies of the same temperature, as a result of H^- opacity. Differential effects due to gravity and CN strength are seen to be small.

Eight-color observations of MK standard stars were used to establish the mean m(7810) - m(10540) color index for normal, unreddened giant stars of each spectral type from K0 III to K4 III, and the calibration indicated in Figure 3 for giants (x's) was used to obtain the corresponding effective temperatures. The results are given in Table I. Further work is underway to evaluate formally the uncertainties in these results and to extend them to other luminosities and temperatures.

Table I. Temperatures for K Giants

Spectral Type	T_{eff}
K0 III	4970 K
K1 III	4780
K2 III	4590
K3 III	4400
K4 III	4210

Our new temperatures for K giants are higher than most previous values (Figure 4) but are consistent with the spectroscopic results of Lambert and Ries (1981). The scales of Kuiper (1938) and Johnson (1966)

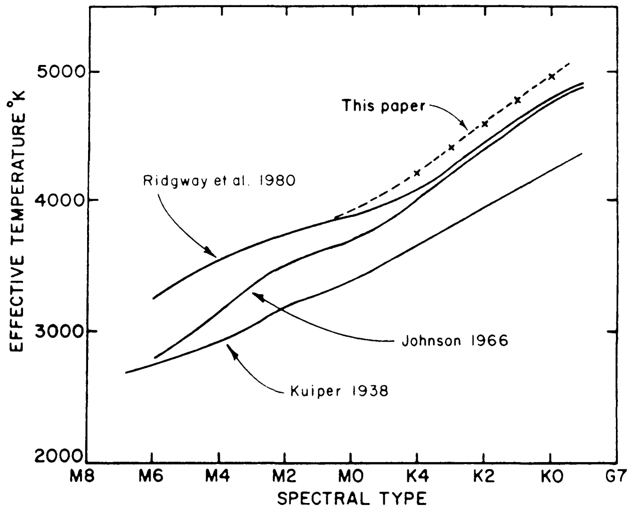

Fig. 4. Effective temperature scales from three previous studies and from the present work.

are both based on the same half-dozen angular-diameter stars (including only one K giant), while the lunar-occultation scale of Ridgway et al. (1980), which is well determined for M giants, is also weak for the G and K stars. The results of Frisk and Bell (1985) also indicate that an upward revision of the temperature scale of Johnson (1966) is necessary for G-K giants, although the revision suggested by Frisk and Bell is somewhat smaller than that suggested here. A more definitive recommendation as regards the proper temperature scale for G-K giants will be discussed in a later paper.

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