51. Effective Temperature Scale of Red Giant Stars

By Takashi TSUJI
Department of Astronomy, University of Tokyo, Tokyo

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1. In principle, empirical determination of effective temperature of a red giant star is possible if apparent angular diameter and apparent bolometric magnitude are known. The present situation is summarized in Fig. 1 in which empirical effective temperatures based on bolometric corrections, now well established (Johnson 1965), and available angular diameters are plotted against $R-I$ color indexes. Generally, the differences of the effective temperatures determined from angular diameters by different observers are several hundreds degrees for the same star and as large as 1000 °K for an extreme case ($\alpha$ Herculis A). Evidently, another argument should be required to establish the effective temperature scale of red giant stars. For this purpose, one possibility could be to apply model atmospheres. Although some difficulties are well known in this approach in cool stars, it can be shown that the present state of art is such that model atmosphere method can at least differentiate between models based on largely different effective temperatures if properly been applied to an analysis of observed spectral energy distributions.

2. The above noted possibility is examined by the use of grids of line-blanketed model atmospheres.*) In Fig. 2, the observed spectral energy distribution of $\alpha$ Tauri (K5III) is compared with the predicted ones from models.**) The model of $T_{\text{eff}}=3800$ °K can be rejected, since the observed flux is too large near the flux peak around 0.8 $\mu$ as compared with the predicted line-blanketed flux (stepwise solid line) and moreover exceeds the line-blocking-free continuum (thin continuous line) which is the maximum possible flux expected from this model. The model of $T_{\text{eff}}=4200$ °K can also be rejected since the predicted flux is too large as compared with the observed

*) The details of these model atmospheres will be published elsewhere.

**) Because of the above noted uncertainty in angular diameters, observed spectral energy distribution can be reliable only in relative absolute scale. Accordingly, the fitting in ordinate scale is done at infrared where the observed flux in relative absolute scale can be matched to any predicted fluxes, since the relative spectral energy distribution is almost insensitive to temperature in Rayleigh-Jeans region. Then the goodness of overall fitting in shorter wavelength region will decide the best model. This method has successfully been applied to a detailed analysis of $\alpha$ Orionis, an M2-supergiant (Tsuji 1976).
The overall best fitting is obtained for the model of $T_{\text{eff}}=4000$ °K. The sensitivity of the predicted fluxes on $T_{\text{eff}}$ as shown in Fig. 2 makes it possible to estimate $T_{\text{eff}}$ with an accuracy of about 100 °K, and we can suggest $T_{\text{eff}} (\alpha \ Tau) = 4000 \pm 100$ °K.

Similar analysis is done for $\alpha$ Herculis A (M5II-III) in Fig. 3. It is noted that the observed flux is too blue as compared with the predicted one from a model of $T_{\text{eff}}=3000$ °K and $T_{\text{eff}} (\alpha \ Her)$ cannot be below 3000 °K. With a model of $T_{\text{eff}}=3200$ °K, the overall fitting is reasonable. Also, the observed flux can be explained by the predicted flux from a model of $T_{\text{eff}}=3400$ °K except in the shortest wavelength region. These results indicate that $T_{\text{eff}} (\alpha \ Her) = 3300 \pm 200$ °K. Similar analyses are extended to other M-giant stars and the results are $T_{\text{eff}}=3900, 3600, 3300,$ and 2600 °K for $\beta$ And (M0III), $\mu$ Gem (M3III), $g$ Her (M6III), and R Leo (M8e), respectively.
The effective temperatures obtained above by the model atmosphere analysis are shown by heavy solid line in Fig. 1 and they nearly coincide with the upper limiting values of the empirical effective temperatures obtained by different angular diameters. It
is interesting to notice that the maximum empirical effective temperature for a star corresponds to the minimum angular diameter which may probably represent the measurement of the highest resolution for the star. In other words, the effective temperature scale obtained by our model atmosphere analysis of observed flux curve, independently of angular diameters, shows a good agreement with the possible best empirical effective temperature scale obtained by angular diameter measurements. The effective temperature scale obtained above is higher by several hundred degrees as compared with the one widely accepted before (Johnson 1965, Lee 1970; dashed line in Fig. 1). This revision will provide interesting consequences on some astrophysical problems. For example, it has long been believed that H$_2$O absorption should be strong in M-giant stars, but actually this was not detected in most non-Mira M-giant stars (e.g. Spinrad and Wing 1969). This is probably because M-giant stars have been thought to be very cool stars, but they now appear to be not so cool and this fact provides a natural explanation why H$_2$O was not found in these stars. Also, it is known that red giant stars follow a well defined sequence in (M$_{bol}$, R−I)-plane (Eggen 1972, 1973) and observational HR-diagram could be reconsidered by the use of our revised T$_{eff}$-R−I calibration.

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