Intrinsic Properties of Carbon Stars. I. Effective Temperature Scale of N-type Carbon Stars

Takashi Tsuji
Tokyo Astronomical Observatory, University of Tokyo, Mitaka, Tokyo, 181 Japan

Received 1981 January 27; accepted 1981 March 7

Abstract. It is shown that the infrared flux method for determining stellar effective temperatures (Blackwell and Shallis 1977; Blackwell, Petford and Shallis 1980) can be applied to cool carbon stars. Although the spectra of cool carbon stars are highly line blanketed, the spectral region between 3 and 4 µm (L-band in the infrared photometry system) is found to be relatively free from strong line absorption. The ratio $R_L$ of bolometric flux to $L$ flux can then be used as a measure of effective temperature. On the basis of the predicted line-blanketed flux based on model atmospheres, with an empirical correction for the effect of 3 µm absorption due to polyatomic species (HCN, C$_2$H$_2$), it is shown that $R_L$ is roughly proportional to $T_{\text{eff}}^3$. The high sensitivity of $R_L$ to $T_{\text{eff}}$ makes it a very good measure of effective temperature, and the usual difficulty due to differential line blanketing effect in the analyses of photometric indices of cool carbon stars can be minimized.

It is found that the majority of N-type carbon stars with small variability (SRb and Lb variables) are confined to the effective temperature range between 2400 and 3200 K, in contrast to M-giant stars (M0 III-M6 III, including SRb and Lb variables) that are confined to the effective temperature range between 3200 and 3900 K. The effective temperatures based on the infrared flux method show good agreement with those derived directly from angular diameter measurements of 5 carbon stars. On the basis of the new effective temperature scale for carbon stars, it is shown that the well known C-classification does not represent a temperature sequence. On the other hand, colour temperatures based on various photometric indices all show good correlations with our derived effective temperatures.

Key words: carbon stars—effective temperatures—line blanketing—spectral classification—stellar atmospheres
Carbon stars play an important role in our understanding of both stars and galaxies. For example, the recent theory of stellar evolution made it possible to predict the details of stellar evolution at the advanced stages (e.g., Sugimoto and Nomoto 1974; Iben 1975). A carbon star could thus be a touchstone for the theory of stellar evolution at such late stages. Although carbon stars represent rather a minor constituent as compared with K–M giant stars in our Galaxy, it is found recently that carbon stars may form a more important population in other stellar systems such as the Magellanic Clouds (Blanco, Blanco and McCarthy 1978). This fact implies that carbon stars cannot necessarily be regarded as peculiar stars but rather they could represent a characteristic stage of normal stellar evolution. This fact also implies that carbon stars can be used as an important tracer of galactic evolution. Also, recent infrared and radio observations have revealed that many carbon stars are embedded in dust and molecular clouds (e.g., Merrill and Ridgway 1979; Zuckerman 1980), which implies that carbon stars are losing mass at a large rate and this has important bearings not only on stellar evolution but also on interstellar chemistry.

One important prerequisite to pursue these problems relating to carbon stars is to have an accurate knowledge of the intrinsic properties of carbon stars. This should in principle be determined from observations of nearby carbon stars. Unfortunately, this problem is still not adequately resolved possibly because of the great complexity of the spectra of cool carbon stars. For example, the effective temperature scale of carbon stars is not available. It is also uncertain whether any of the spectral classification schemes can be considered as a temperature sequence. Recently, spectral classification of carbon stars has been extended to a large sample by Yamashita (1967, 1972, 1975a), and major spectroscopic characteristics of these stars have been well worked out. On the other hand, Richer (1971) pointed out that C-classification is not compatible with colour temperatures based on infrared photometry, and he has proposed a new spectral classification scheme of carbon stars that may be more consistent with colour temperatures. Such an ambiguous situation can exist if either the C-classification does not represent the temperature sequence of carbon stars (e.g., Bergeat et al. 1976a; Scalo 1976), or if the interpretation of infrared photometry is incorrect because of the large differential line-blanketing effect in carbon stars (Yamashita 1975b). More recently, angular diameter measurements have also been made of some cool carbon stars (Ridgway, Wells and Joyce 1977; Ridgway, Jacoby, Joyce and Wells 1980, personal communication; Walker, Wild and Byrne 1979). The temperature scale of carbon stars can, in principle, be determined by this method. At present, however, the number of stars analyzed by this procedure is still too small to provide a definite conclusion. We show in this study a new possibility to settle the issue.

The infrared flux method for determining stellar effective temperature, first proposed by Blackwell and Shallis (1977) and further developed by Blackwell, Petford and Shallis (1980), can be applied to cool carbon stars. This success is due to locating an infrared spectral region that is free from strong line absorption in cool carbon stars. In fact, the $L$ band ($\lambda_{\text{eff}} = 3.4$ μm) measured by the current infrared photometric system can be regarded as a good quasi-continuum in cool carbon stars, and reasonably accurate prediction of the emergent stellar flux can be done on the basis of model