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Red supergiants in the Small Magellanic Cloud: The effects of metallicity on narrow-band classification indices

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Abstract. Narrow-band classification photometry, on a six-color system that measures near-infrared bands of TiO and CN, has been obtained for a set of red supergiants in the Small Magellanic Cloud. To investigate the effects of metallicity on the band-strength indices, comparisons are made to supergiants in the LMC and the Galaxy. Two new variable stars are reported.

1. Introduction

Red supergiants are among the most conspicuous members of young stellar populations, especially at red and infrared wavelengths, and they are useful as distance indicators if absolute magnitudes can be assigned spectroscopically. However, since most spectroscopic luminosity criteria are composition-dependent, we must investigate the extent of this dependence before employing red supergiants as distance indicators for stellar populations of differing metallicity.

MacConnell, Wing, & Costa (1992) have shown that distances to red supergiants can be determined individually from narrow-band photometry on a system that provides an apparent magnitude, a continuum color, and a two-dimensional spectral classification based on measurements of near infrared bands of TiO and CN. Interstellar absorption is found from comparison of the observed color with that expected for the star's TiO strength, together with an assumed interstellar reddening law. The distance then follows from comparing the corrected apparent (near-infrared) magnitude to the absolute magnitude assigned to the star's CN strength. Within the spiral arms of the Milky Way Galaxy, it is reasonable to assume that all red supergiants have approximately solar composition, and that a luminosity calibration of the CN index based on stars in h & χ Persei can be applied to them all. However, Wing & Houdashelt (1992) found that red supergiants in the Large Magellanic Cloud (LMC) have systematically weaker

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CN than stars of the same absolute magnitude in h & χ Persei, and the difference was attributed to the lower metallicity of the LMC. Here we use similar observations of stars belonging to the Small Magellanic Cloud (SMC) to see whether its even lower metallicity results in a further lowering of the CN index. Our observations also provide precise TiO-based spectral types.

2. Observations

The survey for red supergiants in the SMC by Prévot et al. (1983) resulted in a catalogue of 222 objects having V magnitudes in the approximate range 11–14 and objective-prism classifications of "KM", "K5–8", or "M0–1". Although some of the brightest objects were considered likely foreground stars and some of the faintest may be AGB stars, the great majority must be supergiants belonging to the SMC, as has been confirmed by subsequent radial-velocity measurements (Maurice et al. 1987). For this study, we selected 36 radial-velocity members that are sufficiently isolated from their neighbors to allow straightforward aperture photometry. Many of these stars have been classified by Elias, Frogel, & Humphreys (1985) – usually as K5, M0, or K5–M0 – and two of them are the known variables HV 1956 and HV 11402.

Six-color photometry, employing the first six filters of the eight-color system described by MacConnell et al. (1992), was obtained for these stars at the 1.5-m telescope at CTIO on observing runs in 1998 September and 2001 December. Nine of the stars were observed on both runs.

Our temperature classes are in general agreement with previous work, but more precise. Most of the stars classified K5–8 by Prévot et al. (1983) are found to be in the range K3.5–K5, while most of the M0–1 stars were found in the range K4.5–M0. A few of the stars had no measurable TiO and are presumably early K supergiants, and two stars were observed as late as M2.

3. Two new variables

Many red supergiants are variable, showing semi-regular or irregular variations in magnitude and spectral type in time scales of typically 500 to 1000 d. It is therefore not surprising that four of the nine stars observed on both observing runs, about 1175 days apart, showed substantial differences in magnitude and/or spectral type. Two of these are the known variables already mentioned, but the largest variations were shown by two new variables.

In Fig. 1 we show the six-color photometry for PMMR–9 and PMMR–101, each observed twice (here we use the acronym recommended by Lortet (1986) for stars numbered by Prévot et al. 1983). Both varied between type K4.7 and a type later than M2, with corresponding changes in magnitude and continuum color. The type M2.4 appears to be the latest ever recorded for a supergiant in the SMC, although later types have been found for fainter SMC stars which presumably belong to the AGB (Lloyd Evans 1980).

In these six-color "spectra", the TiO molecule is measured at filter 1 and also affects filter 3, while CN absorption is measured at filter 4 and also slightly affects filter 2. Both of these variables are classified as Ib supergiants on the

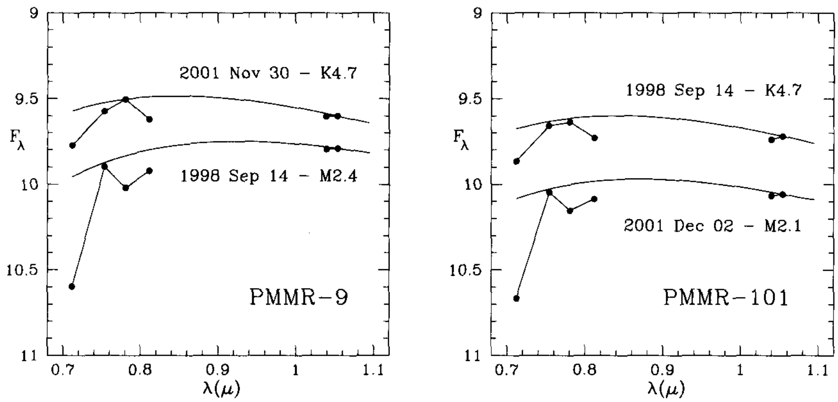

Figure 1. Narrow-band photometry of two new variable stars, each observed twice: (left) PMMR–9; and (right) PMMR–101. Spectral types are based on the strength of TiO at filter 1, while filter 4 is depressed by luminosity-sensitive CN. The ordinate is absolute flux on a magnitude scale. Fitted blackbody curves are shown for comparison.

basis of their CN strength and the usual (solar-metallicity) calibration, but their absolute magnitudes are in the range normally called Ia.

4. Effect of metallicity on the luminosity calibration

To compare the CN strengths of SMC stars to those of Milky Way or LMC stars of similar luminosity, we must be careful to select comparison stars with well-known distances. We have chosen the 18 red supergiants of the Double Cluster h & χ Persei, at a distance modulus of $m - M = 12.0$, to represent the supergiants of our Galaxy, and 16 similar stars of NGC 2100 to represent the LMC (at an assumed distance of $m - M = 18.5$). We assumed $m - M = 18.9$ for the SMC. For the stars of the Double Cluster and NGC 2100, individual corrections for reddening and absorption were determined and applied.

All 45 spectra of the 36 SMC stars show CN absorption of a strength at least that of a giant, and most are in the range of supergiants. If we use the normal (Galactic) calibration of the MK luminosity classes (MacConnell et al. 1992), we find 8 spectra of class III, 10 of class II, 16 Ib supergiants, and 11 Iab supergiants. We found no cases of CN strong enough to qualify as a (Galactic) Ia supergiant.

In Fig. 2 we compare the CN–TiO distributions found in the SMC, the LMC (NGC 2100), and the Galaxy (h & χ Persei). The SMC stars are concentrated on the left side of the figure since most of them are K stars (TiO < 0.25). In terms of CN, the SMC and LMC stars have similar distributions, both showing systematically weaker CN than the Galactic stars. Is this the expected result? One might anticipate that the lower metallicity of the SMC would result in weaker CN strengths, as compared to the LMC – that is, if we are comparing

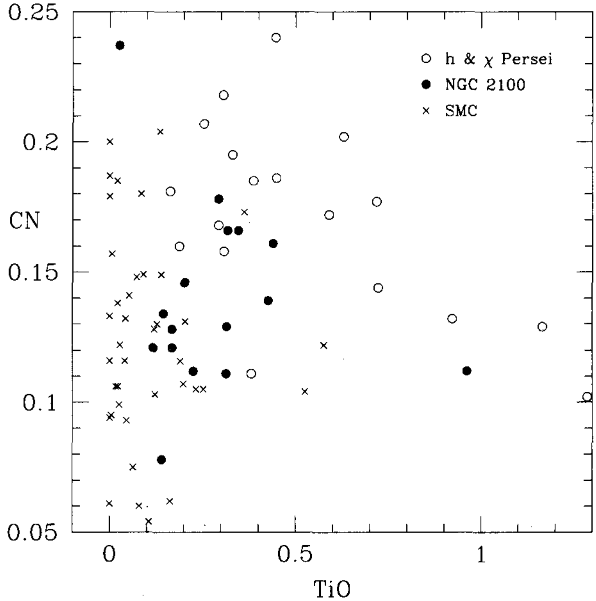

Figure 2. The luminosity-sensitive CN index vs. the temperature-sensitive TiO index (both in mag) for red supergiants in the SMC (×), in NGC 2100 of the LMC (•), and in the Galactic open clusters h & χ Persei (○). For reference, TiO = 0.25 at M0.0 and = 1.0 at M4.0.

stars of similar luminosity. But we find that the stars we have observed in the SMC, which have visual magnitudes between 12.0 and 13.2, are nearly all more luminous – in either M_V or $M(104)$ – than the stars of NGC 2100 or the Iab supergiants of the Double Cluster. Indeed, most of our SMC stars have the absolute magnitudes of Ia supergiants. Clearly, the CN bands are weakened more in the SMC than in the LMC.

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Discussion

Chambliss: μ Cephei is probably the archetypal extreme M-type supergiant. Are there any similar stars in the SMC?

Wing: The brightest SMC supergiants may be similar to μ Cep (M2 Ia) in luminosity, but they have earlier spectral types (K). However, the luminosity comparison requires knowledge of the distance to μ Cep, which I suppose is rather uncertain.

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