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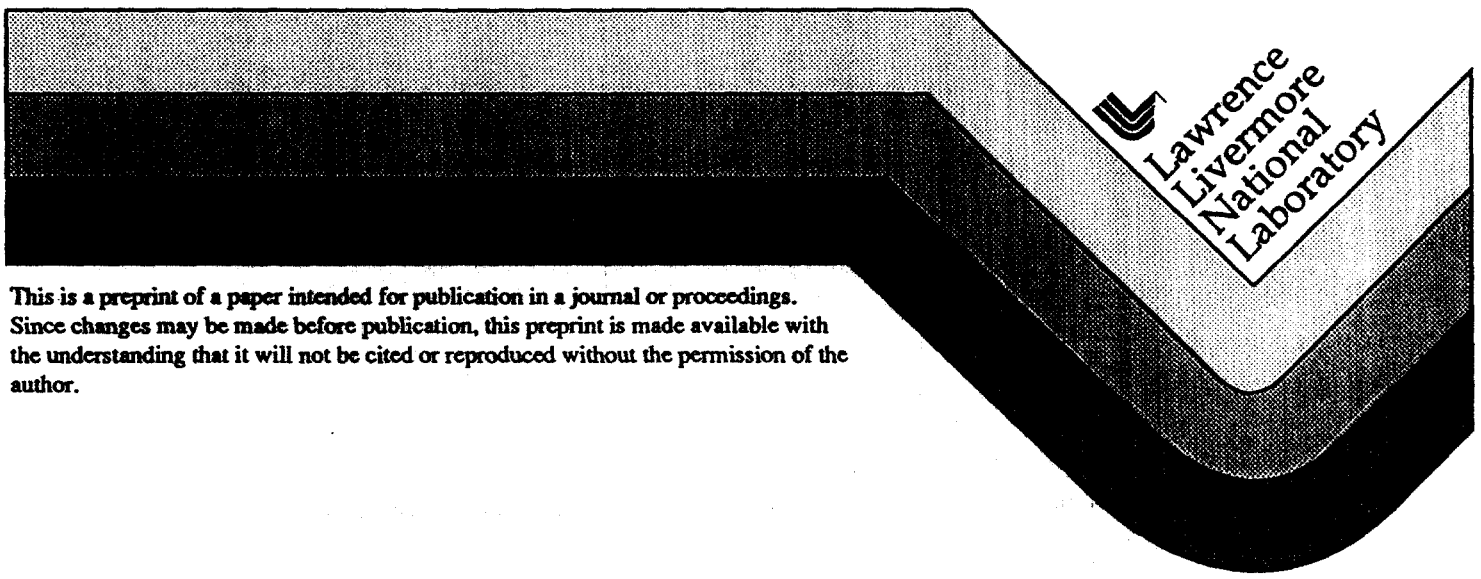

DISCLAIMER

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MACHO OBSERVATIONS OF TYPE II CEPHEIDS AND RV TAURI STARS IN THE LMC

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Abstract

We report the discovery of the existence of RV Tauri stars in the Large Magellanic Cloud. This class of variable star has hitherto been unidentified in the Magellanic Clouds. In light and colour curve behaviour the RV Tauri stars appear to be an extension of the Type II Cepheids to longer periods. A single period–luminosity–colour relationship is seen to describe both the Type II Cepheids and the RV Tauri stars in the LMC.

1 Introduction and Motivation

The RV Tauri stars are semiregular pulsators located between the classical Cepheids and the Long Period Variables in the HR diagram. A defining characteristic of these variables is a light curve which displays alternating deep and shallow minima. Many members of this class exhibit strong infrared excesses indicative of extensive amounts of circumstellar material. From an evolutionary perspective the RV Tauri stars are believed to be low-mass, population II objects in the final stages of their AGB evolution and hence are likely progenitors of planetary nebulae. These stars therefore represent an important probe of this critical phase of late stellar evolution.

Of fundamental importance to our understanding of the evolutionary status of the RV Tauri variables, and their relationship to the Type II Cepheids, is the knowledge of the physical properties

of these stars. Our understanding of their mass and evolutionary state depends critically on their luminosities. However, these luminosities are poorly known.

There are currently no published identifications of RV Tauri stars in the Magellanic Clouds. Furthermore, there is concern that the handful of stars which are globular cluster members (and for which we have some knowledge of their luminosities) are not of the same spectroscopic type or metallicity as the field RV Tauri stars. No definitive period–luminosity relation exists. The most commonly used relation [3] is based on observations of a very small number of low-metallicity globular cluster members and little agreement is seen between this relation and luminosities derived from recent spectroscopic observations of field RV Tauri stars [6].

The MACHO project photometry of Large Magellanic Cloud (LMC) variables provides us with an ideal database to study these variables. This is due to the fact that all stars are at a known common distance, differential reddening is low and large numbers of observations on a common photometric system are available over a continuous time interval of many cycles.

2 Observations and Analysis

The MACHO project has been described by [1] and [2]. Photometric observations of the LMC fields are obtained in a 'blue' (440–590 nm) and 'red' (590–780 nm) bandpass simultaneously. (Hereafter we refer to these bandpasses as $V_{\rm MACHO}$ and $R_{\rm MACHO}$ respectively.) This paper is based on photometry from 22 well-sampled fields concentrated along the bar of the LMC and covering a time span of up to about 1300 days.

A number of selection criteria were applied to the MACHO project variable star database in order to produce a list of possible Type II Cepheid and RV Tauri star candidates:

- 8 d < period < 100 d
  (shorter period type II Cepheids are present in the MACHO project database but the data were not available for this project);
- $18.5 - 3\log 10(\text{period}) < R < 18.0$
  (the first limit was used to exclude the Type I Cepheids);
- $0.3 < (V\text{–}R) < 0.6$.

The $V_{\rm MACHO}$ and $R_{\rm MACHO}$ light curves of the resulting selection of approximately 250 variables were searched for periodicities using a standard fourier-type period-finding code. The phased light curves were then visually examined in order to classify the variables. The phased light curve of each Type II Cepheid or RV Tauri candidate was fitted with a truncated Fourier series of the best period and up to the 9th order. The fourier coefficients (R_{21}, Φ_{21}, R_{31}, Φ_{31}, etc.) were calculated from this light-curve fitting.

3 Results

3.1 Lightcurves

Twenty-seven Type II Cepheid and RV Tauri candidates were discovered. A cross check of these variable with the list of Type II Cepheids given in [4] revealed six stars in common. Phased $V_{\rm MACHO}$ light and $(V\text{–}R)_{\rm MACHO}$ colour curves for four of the new Type II Cepheid and RV Tauri variables are shown in Figure 1.

In general it was found that type II Cepheids with periods greater than ~20 days display increasing variability in the depth, shape and phasing of their light curve minima. The periodograms of these stars also exhibit increasing strength in the subharmonic frequency (or the double period). Classic RV Tauri behaviour [5] is displayed by most of the stars with 'single' or fundamental periods greater than about 20 days, that is:

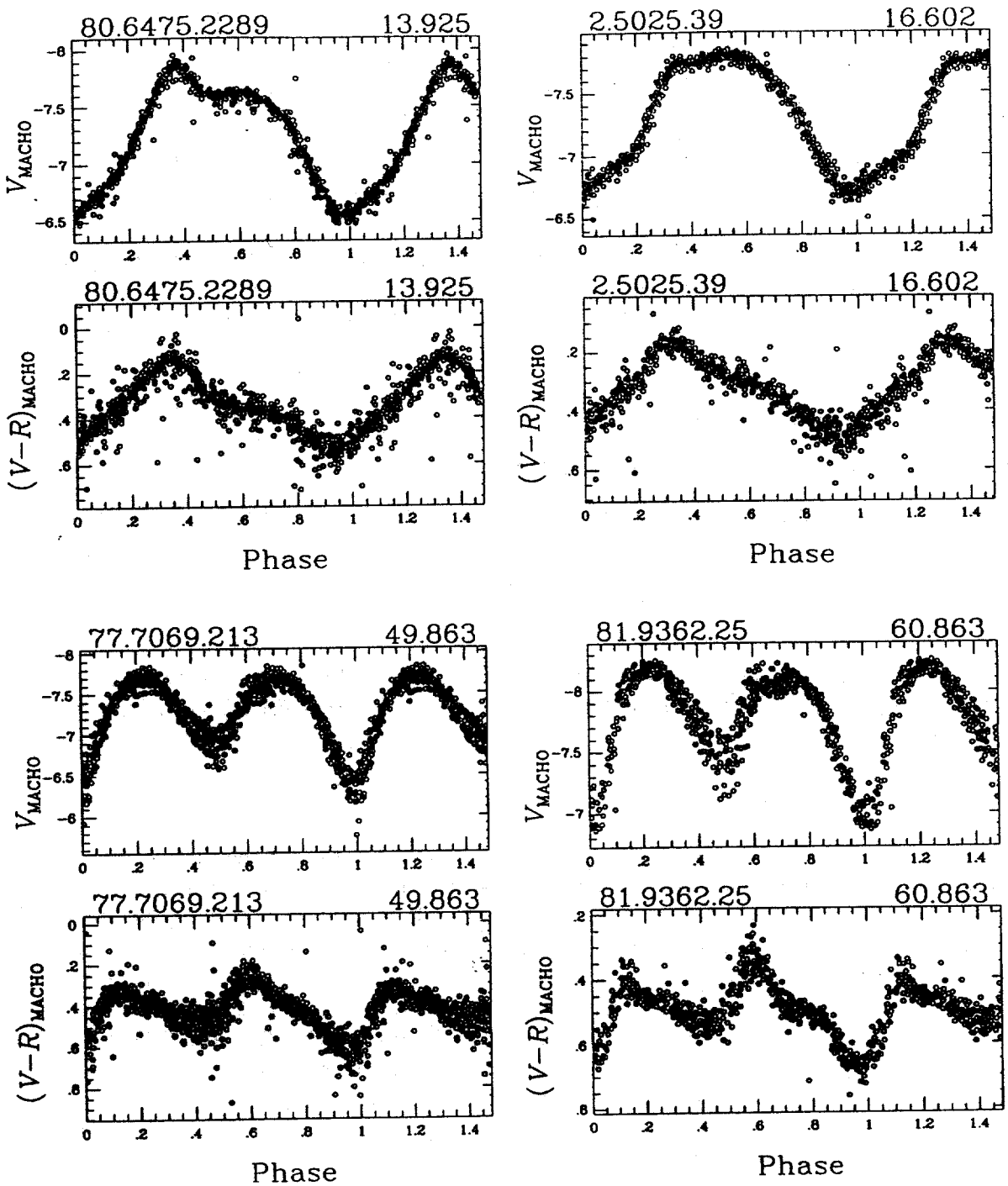

Figure 1: The top four panels display the MACHO light and colour curves for two new examples of Type II Cepheids in the LMC (MACHO stars 80.6475.2289 and 2.5025.39). Two examples of the newly-discovered LMC RV Tauri stars (MACHO stars 77.7069.213 and 81.9362.25) are shown in the lower four panels. The Type II Cepheids are plotted on the 'single' or fundamental period, while the RV Tauri stars are plotted on the 'double' or formal period. These periods are indicated to the upper right of each panel. The variables are plotted between phases 0.0 and 1.5 in order to reveal continuity. The large ticks on the vertical axis are 0.5 magnitudes for the light curves and 0.2 magnitudes for the colour curves.

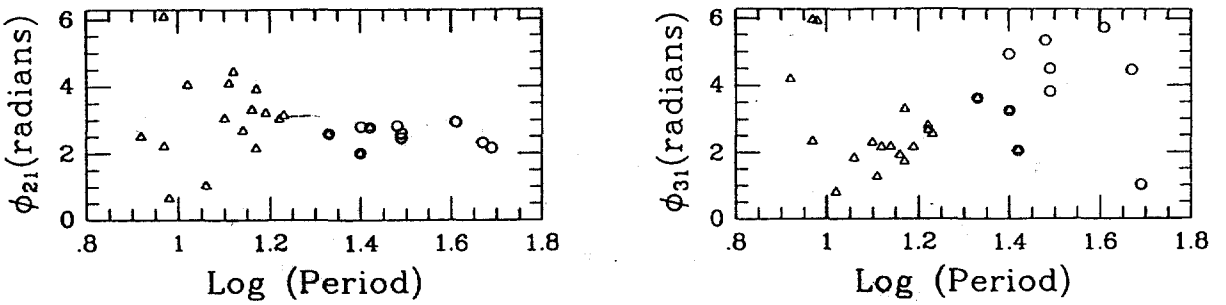

Figure 2: The fourier parameters Φ_{21} and Φ_{31} are plotted *vs* log P. Some difference in behaviour is seen in the Φ_{21}–log P diagram for the Type II Cepheids and the RV Tauri stars with a demarcation at about log P = 1.3 (20 days). The Φ_{31}–log P diagram shows possible structure at about log P = 1.0 (10 days).

- alternating deep ('primary') and shallow ('secondary') minima;
- secondary minima more variable than primary minima;
- bluest colours during the rising branch of the light curve, particularly during the rise from the secondary minima;

3.2 Fourier decomposition

The fourier decomposition parameters Φ_{21} and Φ_{31} are plotted *vs* log P in Figure 2. This figure shows possible structure at periods around 10 days and 20 days but the small sample size limits the analysis of the fourier parameters.

3.3 Period–Luminosity relationship

The MACHO database of LMC photometry allows us a direct interpretation of the luminosity and hence the P–L and P–L–C relations for these variables. Although the photometric calibration to the standard system still needs to be refined, we can examine the P–L and the P–L–C relations of the Type II Cepheids and RV Tauri stars in the LMC using the MACHO bandpasses and the current (approximate) calibration. The reddening-free index W_R $(= R - 4(V - R))$ is a projection of the P–L–C relation which removes the largest part of the effect of differing effective temperatures and differential absorption [2]. The plot of W_R *vs* log P is shown in Figure 3. This figure indicates that the RV Tauri stars are a direct extension of the Type II Cepheids to longer periods and that these population II variables are more accurately represented by a P–L–C relation. This strong link between the behaviour of the Type II Cepheids and the RV Tauri stars may be a reflection of an evolutionary connection between these two classes of variables.

4 Future Work

A number of refinements of and extensions to the above research need to be made:

- A more accurate transformation from $V_{\rm MACHO}$ and $R_{\rm MACHO}$ magnitudes to the standard system is now available and this transformed data will allow us to produce a definitive P–L or P–L–C relation for Type II Cepheids and RV Tauri stars;
- The selection criteria on the MACHO variable star database will be relaxed, to include variables with longer periods and redder colours in order to discover additional LMC RV Tauri stars;

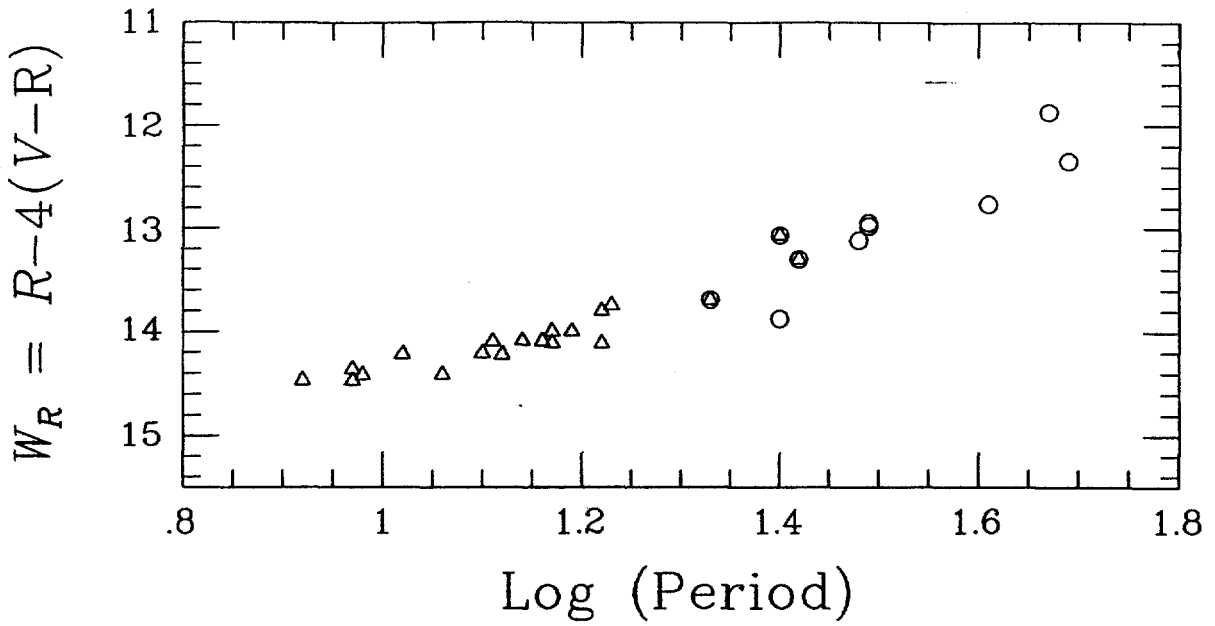

Figure 3: Period–luminosity–colour relation for the Type II Cepheids and RV Tauri stars in the LMC. The reddening-free index W_R *vs* is plotted versus log P. Type II Cepheids (triangles) and RV Tauri stars (circles) are plotted using the 'single' or fundamental period. Intermediate stars which show some characteristics of both classes are plotted using both symbols.

- A larger portion of the MACHO project database may be examined to increase the current sample of Type II Cepheids and RV Tauri stars in the LMC and SMC;
- A more detailed journal paper will be submitted in the near future. This will include all MACHO light curves and finder charts for the LMC Type II Cepheids and RV Tauri stars discovered to date.

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