Physical parameters of RR Lyrae stars from multicolor photometry and Kurucz atmospheric models

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Abstract

The most comprehensive photometric material exists for RR Lyrae (RRL) stars in the Johnson-Cousins system $UBV(RI)_C$. In this system the colors of the Kurucz atmospheric models are available allowing to determine the effective temperature and surface gravity as a function of phase. Using the $UBV(RI)_C$ photometry of the RRab star SU Dra as an example we determine the phase intervals where the quasi-static atmosphere approximation (QSAA) is valid, i.e. where the Kurucz atmospheric models do reproduce the observed $UBV(RI)_C$ colors sufficiently. From the phases where QSAA is a good approximation we determine metallicity and interstellar reddening of SU Dra.

Introduction

The **quasi-static atmosphere approximation** (QSAA) for pulsating stars was introduced by Ledoux & Whitney (1960): *"The simplest approach is to assume that at each phase, the atmosphere adjusts itself practically instantaneously to the radiative flux coming from the interior and to the effective gravity*

$$g_e = \ddot{R} + G\mathcal{M}/R^2$$

where R and $\ddot{R}$ are the instantaneous values of the radius and the acceleration, which is supposed uniform throughout the atmosphere", $\mathcal{M}, G$ are the stellar mass and the Newtonian gravitation constant, respectively.

The purpose of the poster is to find the phases φ of the RRab star SU Dra in which QSAA valid i.e. the static atmospheric models of Kurucz (1997) reproduce the observed colors and to draw some general conclusions.

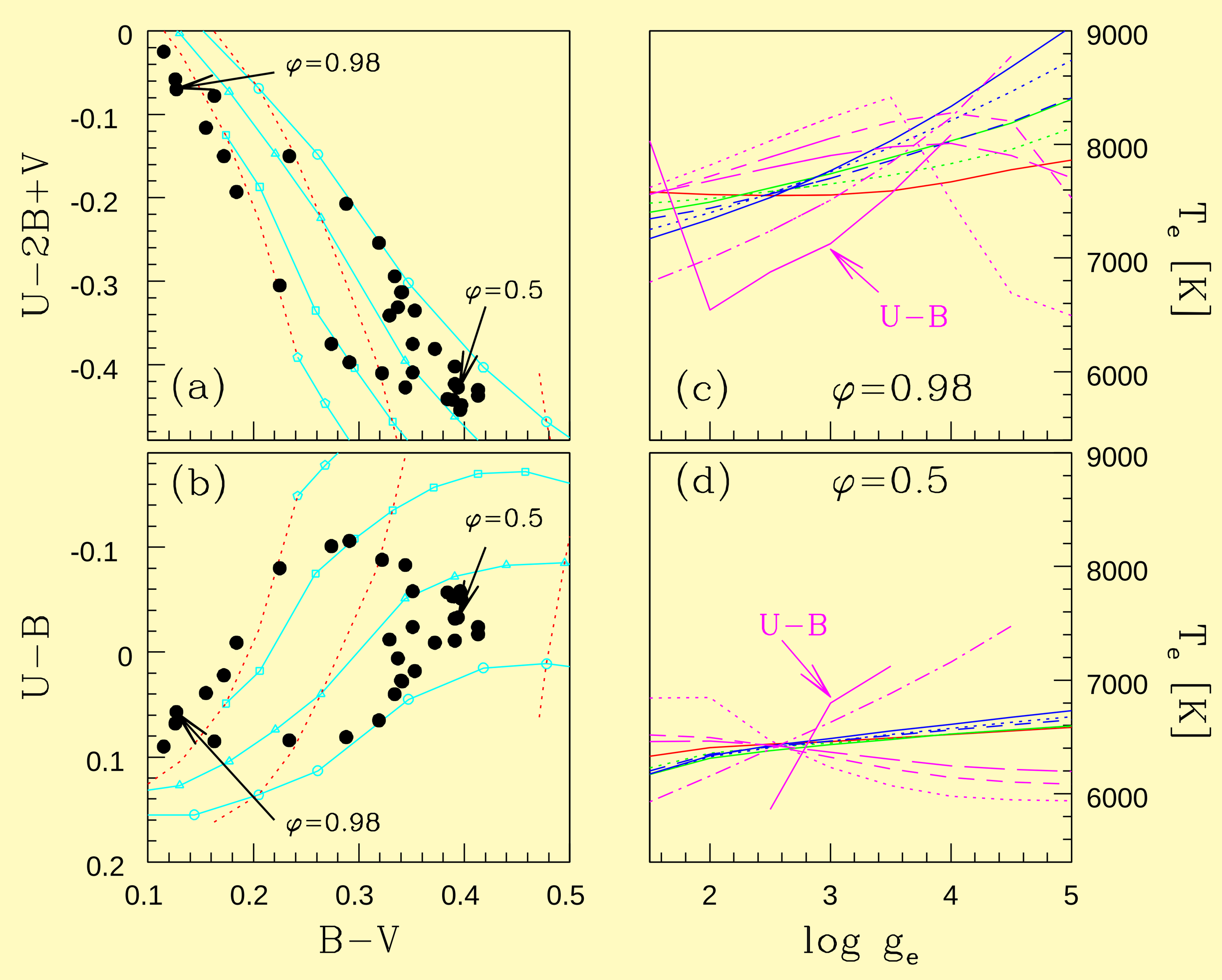

Fig. 1. Color-color diagrams $(U-2B+V, B-V)$, $(U-B, B-V)$ extracted from the Kurucz-tables for $[M] = -1.6$, $E(B-V) = 0.015$. Lines: iso-gravity, **panel (a)**: from top to bottom $\log g_e = 2, 3, 4, 5$, **panel (b)**: from top to bottom $\log g_e = 5, 4, 3, 2$. Dotted: isotherm, from left to right $T_e = 8000, 7000, 6000$ K. Filled circles: color-color loops of SU Dra. **Panels (c), (d)**: the functions $T_e^{(\mathrm{CI})}(\log g_e)$ for all possible color indices CI at phases $\varphi = 0.5, 0.98$. Red: $R-I$, green: $V-R, V-I$, blue: $B-V, B-R, B-I$, magenta: $U-V, U-B, U-2B+V, U-R, U-I$.

A technical remark. In Fig. 1d the function $T_e^{(U-B)}(\log g_e)$ is not single-valued because of the non-monotonicity of the iso-gravity curve $\log g_e = 2.5$ in Fig. 1b. The grid of the Kurucz tables is not dense enough to determine both possible values, therefore, it is an interpolation artifact that $T_e^{(U-B)}(\log g_e = 2.5)$ intersects the other curves at $\log g_e \approx 2.8$. To avoid problems like this it is practical to use the hybrid color index $U-2B+V$ instead of $U-B$.

Results & discussion

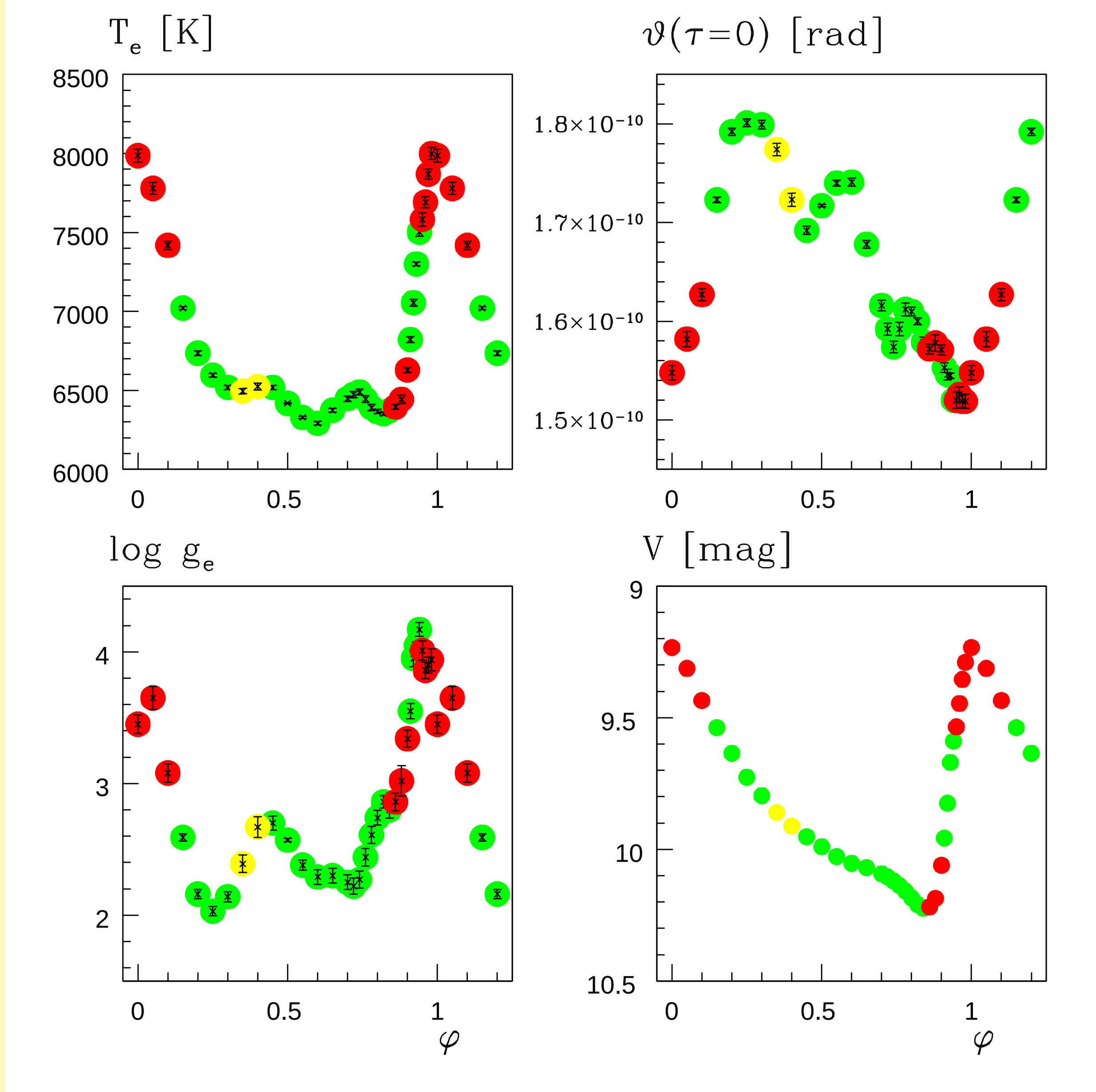

Fig. 2. Variation of $\log g_e$, T_e, $\vartheta(\tau=0)$, and for orientation the mean light curve V of SU Dra. Green points: from the different pairs of the color indices $\Delta T_e < 27$ K and $\Delta \log g_e < 0.067$. Yellow points: $\Delta \log g_e > 0.067$. Red points: $\Delta T_e > 27$ K and $\Delta \log g_e > 0.067$.

Color-color diagrams were constructed from the combinations of CI_1 and $\mathrm{CI}_2: U-2B+V, U-V, U-R, U-I, B-V, B-R, B-I, V-R, V-I, R-I$ having one CI at least with U, the number of the combinations is

$$\binom{10}{2} - \binom{6}{2} = 30.$$

The results $T_e(\varphi)$, $\log g_e(\varphi)$, the half angular diameter of the zero optical depth $\vartheta(\tau=0,\varphi)$, and the light curve $V(\varphi)$ are plotted in Fig. 2. (For determining $\vartheta(\tau=0,\varphi)$ see Barcza 2003). Green symbols indicate the phases where QSAA is a good approximation.

Observed bump and hump in the light curve as well as theoretical studies indicate two shock waves hitting the atmosphere of an RRL star like SU Dra (Smith 1995). Our curves $T_e(\varphi)$, $\log g_e(\varphi)$, $\vartheta(\varphi)$ at $\varphi \approx 0.4$ indicate clearly that an additional shock wave (a "jump") hits the atmosphere. Its presence is indicated by a small change in the slope of the light curve $V(\varphi)$ and by a moderate increase of $\Delta \log g_e(\varphi)$, challenging the validity of QSAA for a phase interval of length 0.1 i.e. for the yellow points.

A by-product is plotted in Fig. 3: in the "green phases" $\varphi = 0.5, 0.15$ we determined the variation of ΔT_e, $\Delta \log g_e$ as a function of $[M]$, $E(B-V)$. The minima of the curves verifies the assumptions $[M] = -1.6$, $E(B-V) = 0.015$ with the reasonable small errors ± 0.2, ± 0.01. This metallicity and reddening were obtained purely from applying five color photometry of good quality for the tranquil (i.e. shock-free) phases of SU Dra and Kurucz atmospheric models without invoking spectroscopy or Preston index.

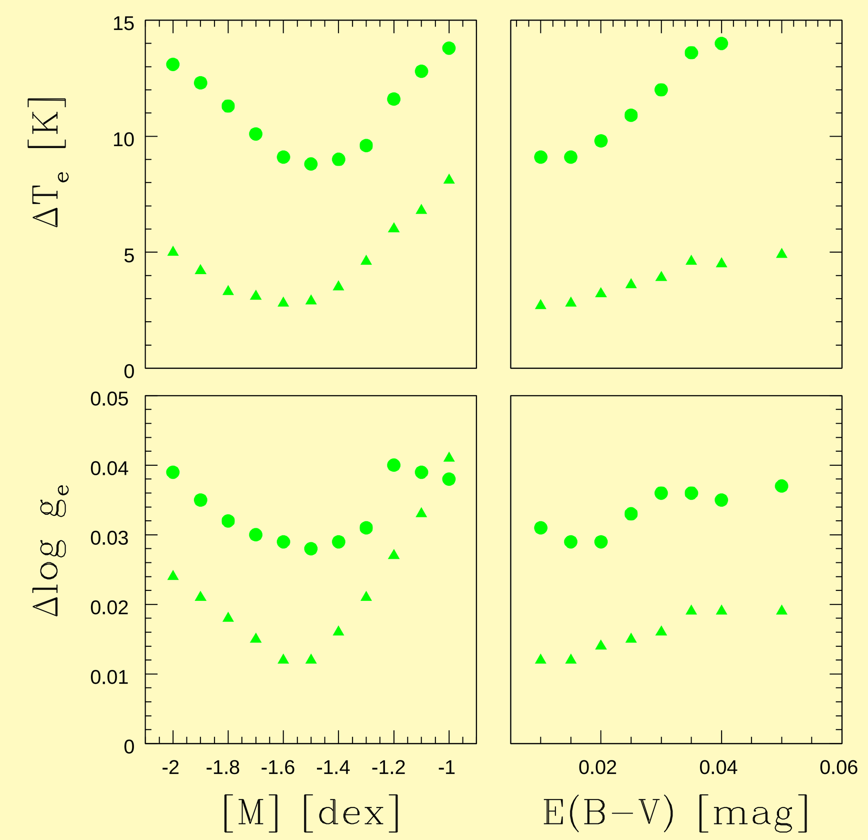

Fig. 3. The variation of the standard error ΔT_e and $\Delta \log g_e$ as a function of metallicity $[M]$ and $E(B-V)$, respectively. Triangles: $\varphi = 0.5$, circles: $\varphi = 0.15$.

$T_e(\varphi)$ and $\log g_e(\varphi)$ from different color-color loops

The color-color diagrams $(U-2B+V, B-V)$, $(U-B, B-V)$ of the Kurucz models for metallicity $[M] = -1.6$ and reddening $E(B-V) = 0.015$ of SU Dra (Liu & Janes, 1990) and the loop of SU Dra (Barcza, 2002, Table 7) are plotted in Fig. 1. In analogy with the Strömgren gravity index $u - 2v + b$ **we introduced the hybrid color index** *U-2B+V* which is more useful because the iso-gravity curves are monotonous is the color range of an RRL star. At a phase point of a color-color diagram $(\mathrm{CI}_1, \mathrm{CI}_2)$ we construct two functions: $T_e^{(\mathrm{CI}_i)}(\log g_e)$, $i = 1, 2$, and their intersection gives a pair T_e, $\log g_e$ belonging to this phase and color-color pair. The technique is illustrated by Fig. 1c,d showing the functions CI= $U-2B+V, U-B, U-V, U-R, U-I, B-V, B-R, B-I, V-R, V-I, R-I$ for $\varphi = 0.5, 0.98$.

We determine the functions $T_e^{(\mathrm{CI})}(\log g_e)$ of all physically suitable color-color diagrams and compute the average of T_e, $\log g_e$ from the intersections for all phases. QSAA is valid in a phase if T_e, $\log g_e$ from the different color-color pairs show a random distribution around the average and their standard errors ΔT_e, $\Delta \log g_e$ are small. From the point of view of QSAA the two extremes were found in the neighborhood of $\varphi = 0.5, 0.98$: $T_e(\varphi=0.5) = 6418 \pm 3$K, $\log g_e(\varphi=0.5) = 2.57 \pm 0.01$ and $T_e(\varphi=0.98) = 7999 \pm 38$K, $\log g_e(\varphi=0.98) = 3.94 \pm 0.08$.

Remark. It is interesting to note that from the color combinations of $\mathrm{CI}_i = B-V, \ldots, R-I$, $i = 1, 2$ solely we find $T_e(\varphi=0.98) = 7601 \pm 17$K, $\log g_e(\varphi=0.98) = 2.56 \pm 0.06$. If we take $\mathrm{CI}_1 = U-B$ and $\mathrm{CI}_2 = B-V, \ldots, R-I$ we find $T_e(\varphi=0.98) = 7413 \pm 115$K, $\log g_e(\varphi=0.98) = 1.71 \pm 0.04$. These differences show clearly that QSAA is a bad approximation at $\varphi \approx 0.98$. Furthermore, reliable values T_e, $\log g_e$ can be obtained if all color index pairs containg at least one U are used because atmospheric effective gravity of an RRL star can be measured properly by measuring the Balmer jump which is covered in the Johnson color system by U only.

References

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