THE STELLAR PHOTOSPHERE-HYDROGEN IONIZATION FRONT INTERACTION IN CLASSICAL PULSATORS

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Introduction

Period-colour (PC) relations for RR Lyraes and classical Cepheids have been studied quite extensively[2]. RR Lyraes have shallow/ sloped relations at minimum/maximum light, whilst long-period ($P > 10$ d) Cepheids exhibit sloped/ flat PC relations at minimum/ maximum light. The differences in the PC relations for Cepheids and RR Lyraes can be explained based on the relative location of the hydrogen ionization front (HIF) and stellar photosphere which depends on their position on the Hertzsprung-Russell diagram. In this work, we extend the study to include the type II Cepheids (BL Her and W Vir) using the OGLE-IV data on the observational front and MESA-RSP[3] on the theoretical front.

Data and Methodology

Source	Band	$N_{\rm T2C}$	$N_{\rm BL\ Her}$	$N_{\rm W\ Vir}$	$N_{\rm pW\ Vir}$	$N_{\rm RV\ Tau}$
Bulge	V	517	221	193	18	85
	I	873	372	336	30	135
LMC	V	243	76	92	24	51
	I	253	80	96	25	52
SMC	V	52	20	15	7	10
	I	52	20	15	7	10

The photometric light curve data are fitted with the Fourier sine series:

$$m = m_0 + \sum_{k=1}^{N} A_k \sin(2\pi k x + \phi_k),$$

where the phase x is calculated as:

$$x = \frac{(t - t_0)}{P} - \text{int}\left(\frac{t - t_0}{P}\right),$$

where t_0 is the epoch of maximum brightness and P is the pulsation period.
From the Fourier-fitted light curves, we obtain colour at maximum, minimum and mean light as:

$$(V-I)_{\rm max} = V_{\rm max} - I_{\rm phmax},$$
$$(V-I)_{\rm min} = V_{\rm min} - I_{\rm phmin},$$
$$(V-I)_{\rm mean} = V_{\rm mean} - I_{\rm mean},$$

where $I_{\rm phmax}$ and $I_{\rm phmin}$ correspond to the I-magnitude at the same phase as that of $V_{\rm max}$ and $V_{\rm min}$, respectively.

Extinction correction:
(i) LMC & SMC[4]:

$$A_V = 3.32 \times E(B-V),$$
$$A_I = 1.94 \times E(B-V).$$

(ii) Bulge[1]:

$$A_{K_s} = 0.689 E(J-K_s),$$
$$\frac{A_{K_s}}{A_V} = 0.114; \frac{A_I}{A_V} = 0.479.$$

PC relations for T2Cs

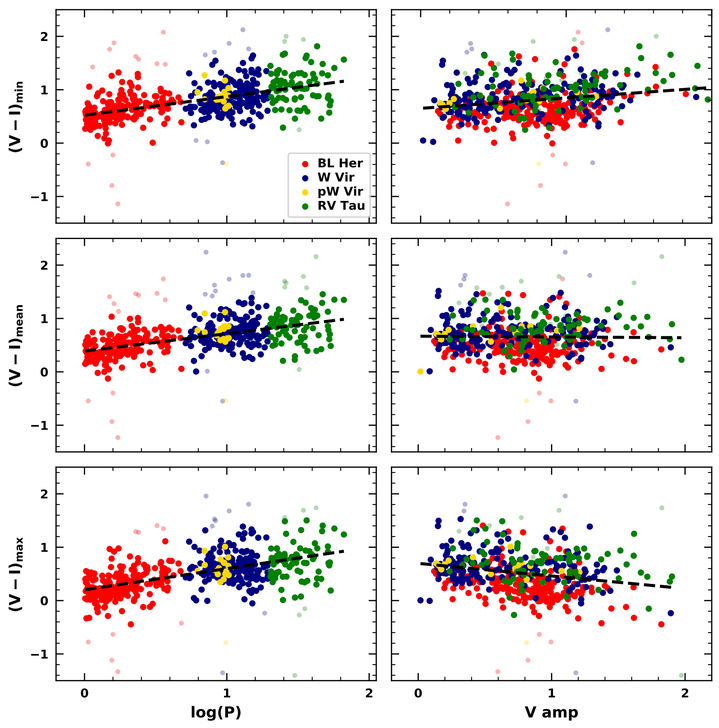

Fig.: PC and AC relations for T2Cs in the Bulge from OGLE-IV at minimum, mean and maximum light.

1. W Vir exhibit flat PC_{max}, sloped PC_{min}, similar to long period Cepheids
2. BL Her exhibit sloped PC_{max}, sloped PC_{min}, similar to short period Cepheids

HIF-photosphere distance from models

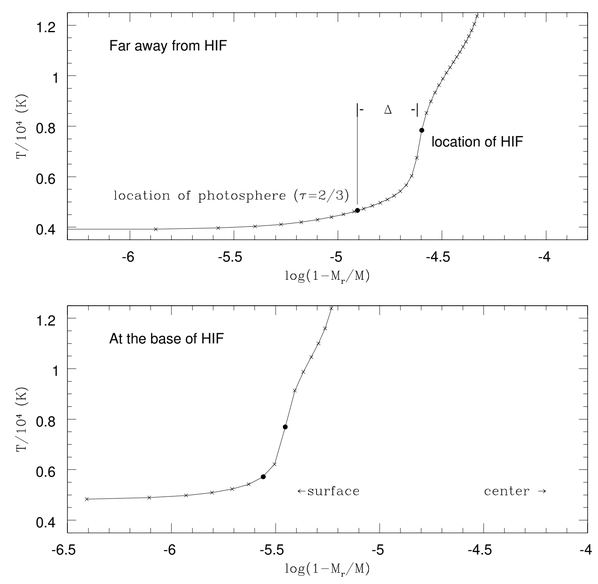

Fig.: Distance (Δ) between HIF and stellar photosphere as function of $\log(P)$ at max and min light[2].

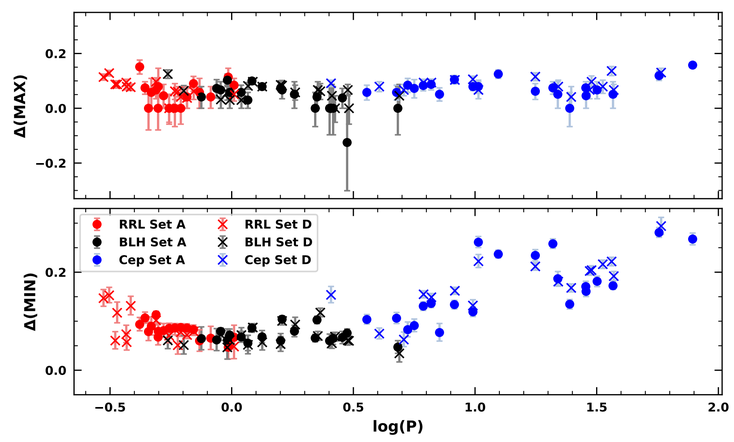

Fig.: HIF-photosphere distance (Δ) as function of $\log(P)$ at max and min light from our models.

Behaviour of HIF-photosphere interaction explained

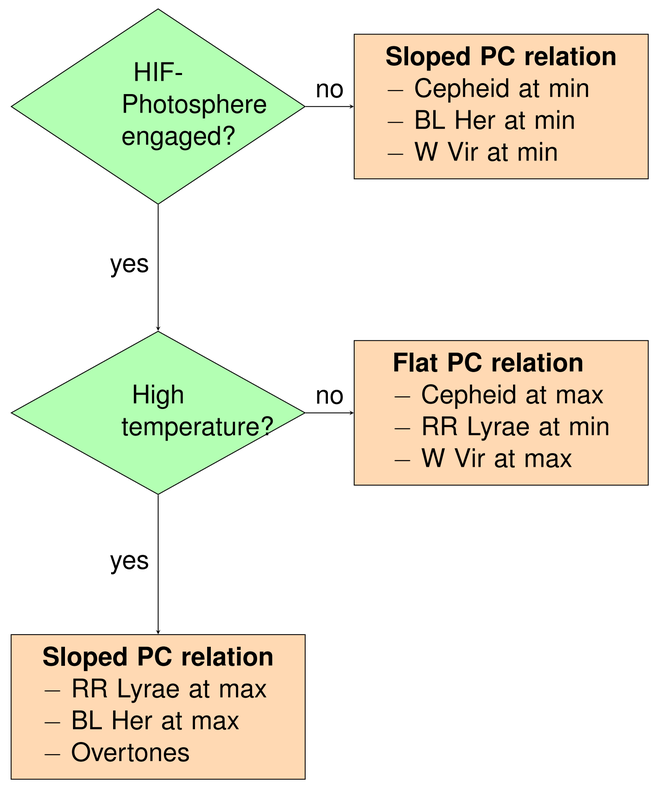

Fig.: The HIF-photosphere interaction theory

- Engaged HIF-photosphere: temperature (and colour) same for both layers.
- Colour becomes independent of global stellar parameters, like period; thus, flat PC relations.
- $\frac{L}{M} \uparrow$ and/or $T_{\rm eff} \downarrow \Rightarrow \Delta \uparrow$.
- $\frac{L}{M} \downarrow$ and/or $T_{\rm eff} \uparrow \Rightarrow \Delta \downarrow$.

Conclusions

1. We have analysed a broad spectrum of variable star types- RR Lyraes, type II Cepheids (BL Her and W Vir) and classical Cepheids using the OGLE-IV data. It is their different locations on the HR diagram that may explain the HIF-photosphere interaction and thus, their PC relations.
2. The HIF and stellar photosphere are engaged and co-moving at maximum light for classical Cepheids, which results in a flat PC slope at maximum light. However, they are disengaged at minimum light and thus, we observe a significant slope in PC_{min}.
3. For RR Lyraes, the HIF and stellar photosphere are engaged during both minimum and maximum light; however, at maximum light, the temperature at which hydrogen starts to ionize appreciably is much more sensitive to temperature than at the temperatures associated with minimum light, even though the range of densities are similar. This results in a flat PC_{min} slope but a significant slope in PC_{max}.
4. BL Her stars are cooler and brighter than RR Lyraes; thus we suggest that the HIF is further inside the mass distribution, thereby increasing the distance between the HIF and stellar photosphere.
5. We have not computed W Vir stars using MESA; however, similar locations of W Vir stars and classical Cepheids on the HR diagram and similar behaviour of PC relations for both suggest similar HIF and stellar photosphere interaction.

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