A Bayesian Approach to Searching for Nonlinearity in the Cepheid Period-Luminosity Relation

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1. Introduction

The Cepheid Period-Luminosity (PL) relation is of vital importance in Astrophysics sincde it provides a CMB independent distance scale that can potentially estimate Hubble's constant to an accuracy of 1-3% (Riess et al 2016 and references therein). A precise determination of H0 will lead to insights into the nature of dark energy and a ccomparison with CMB estimates will provide a rigorous test of the standard cosmological model.. Further a definitive indication of non-linearity and the use of the PL relation at different pulsation phases can lead to strong constraints on the mass-luminosity (ML) relation obeyed by Cepheids. This in turn jas conseqences for Cepheid internal physics such as the extent of convective overshoot.

Previous work (Bhardwaj et al 2016, B16 and references therein)) has used both parametric and non-parametric tests that suggest nonlinearity in the LMC mean light relation. These include standard F tests, testimators and random walk methods (and the Davies test (B15). We note that with the addition of LMC Shallow Survey (SS) data, some of these nonlinearities at mean light disappear at optical wavelengths. However when considered as a function of pulsation phase, these nonlinearities are very evident and pronounced at certain phases.

2. Data

Here we describe recent efforts to dedtermine nonlinearity using Bayesian methods. The photometric mean magniitudes for optical V and I band Cepheids in the LMC are taken from the OGLE-III survey (Soszynski et al. 2008). There are 1849 fundamental mode (FU) and 1238 first overtone (FO) mode Cepheids in the LMC. We augment this sample with mean magnitudes from the OGLE-III Shallow Survey (Ullaczyk et al 2013). The mean magnitudes for the LMC in the optical are corrected for reddening using the maps of Haschke et al (2011) with the adopted reddening law of Cardelli et al (1989).

We retain sources with 12 < V<19 in V and all sources for I. Our noise model is $X_{model} - X_{measured} = N(0,\sigma^2)$ for both V, I bands.

3. Theory

Data Y, models M_k, M_j. Then the Bayes factor for comparing the two models is

$$B(k,j) = \frac{p(Y \mid M_k)}{p(Y \mid M_j)}$$

where p(Y | M) is the marginal likelihood $p(Y \mid M) = \int p(Y \mid \vartheta_k, M) p(\vartheta_k \mid M) d\vartheta_k$

Model 1: X = a0 + a1*logP

Model 2: X = yk + a1*(logP-k), where a1=a1lo if logP<k, else a1=a1hi,where k=1.Model 2 is continuous at logP=k.

Priors on both models (after X, and logP have been zero-meaned):

For V, a0=N(0.1), yk=N(μ,1), where μ is the average value of V around the break point.

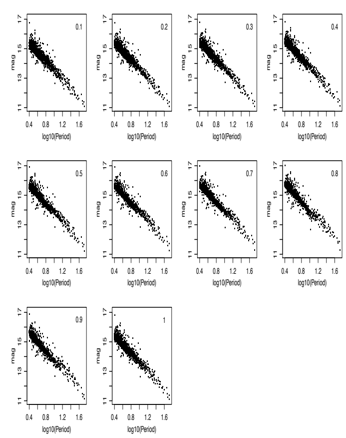
For I, a0 = N(0, 0.25), yk=N(μ,0.25), where μ is the average value of I around the break point.

For V, the visual mean of alpha = atan1(a1) is -1.25 with max. range (-1.36, -1.1). So prio on alpha=N(-1.25,0.1).

Log10(σ) = U(-2,-1). For I, the visual mean of alpha = atan(a1) is atan(12-15.5)/(1.6-0.4)) =-1.24 with rane±2. So

Adopt alpha = N(-1.24,0.2), log10(σ)=U(-2,-1). For both V,I, we draw 10^5 samples

4. Results



Our preliminary indications from the Bayesian analysis suggest no evidence of a break at logP=1 at mean light With the data considered in this paper. This is in agreement with the results in B15. The plots to the left show the I band LMC PL relation at different pulsation phases.

These plots do show a clear "change of behavior" at logP=1. However, our preliminary Bayesian analysis does not provide evidence of a break.

6. Conclusions and Future Work

The results are somewhat puzzling given that previous work has demonstrated the variable nature of the multiphase PL relation, and given the definitive variable nature of the Period-Color (PC) relation as a function of phase (Bhardwaj et al 2016). We also note there is very strong evidence for the physical cause of nonlinearities in PC relations – the interaction of the hydrogen ionization front and stellar photosphere as the star pulsates. PL relations are indeed connected to PC relations through the Period-Wesenheit (PW) relation.

7. References

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