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Wide-Field Variability Surveys: A 21st Century Perspective

Applying survival analysis on the Cepheid period-luminosity relation at 70 μm

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Abstract.
The survival analysis is a type of statistical technique to deal with data that has upper or lower limits. In this work, I demonstrate an example of applying the survival analysis to re-derive the Cepheid period-luminosity relation at 70 μm, because about 2/3 of the currently available data only contains upper limits in flux.

1 Introduction and motivation

The first observation of Cepheids at 70 μm (with *Spitzer's* MIPS) was presented in [1] (hereafter MAR10) for 29 Galactic Cepheids. However, only 9 Cepheids were detected and possessed the 70 μm photometry. Based on these 9 Cepheids, MAR10 derived the first-ever 70 μm period-luminosity (P-L) relation. For the other 20 Cepheids, MAR10 recorded their 3σ upper limits in flux (or lower limit in magnitude). Measurements with upper limits are not new in astronomy: this kind of data is known as censored data, and statistical techniques that deal with censored data are called survival analysis (e.g., see [2–4]). Therefore, the goal of this work is to re-derive the 70 μm P-L relation using the survival analysis to include Cepheids with upper limit detections.

2 Data and methods

The 70 μm photometry (both detected & lower limits) of these Cepheids were taken from MAR10 (their Table 5). I adopted the "new" distances of the 28 Cepheids from Table 1 of MAR10 (only one Cepheid does not have this "new" distance). The 70 μm magnitudes were then converted to absolute magnitudes with the adopted distances. Extinction is ignored since it is negligible in the mid-infrared (MAR10). To re-derive the P-L relation, I used the code `ASURV` ([5], publicly available at `http://ascl.net/1406.001`), to fit a linear regression to the data.

3 Analysis and (preliminary) results

The EM (expectation-maximization) algorithm and the Buckley-James method available from `ASURV` were applied to fit the 70 μm photometry which included the censored data. Since the P-L relation presented in MAR10 was fitted with weighted linear least squares (LSQ) regression, and current

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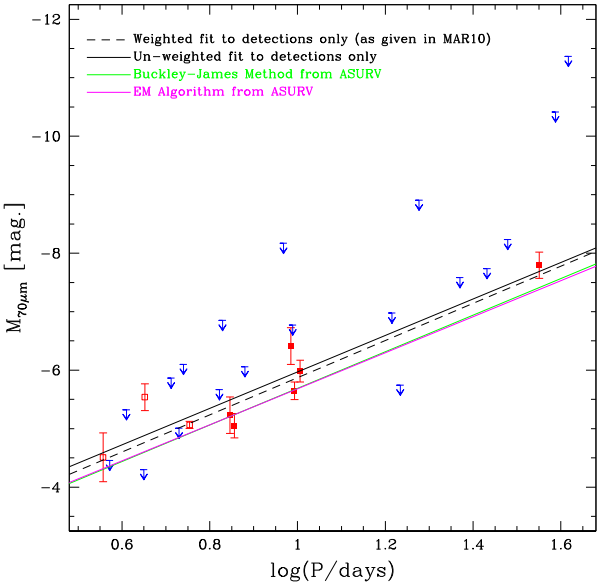

Figure 1. Fitted 70 μm P-L relation with various linear regression methods. Red squares are for fundamental mode (filled symbols) and first overtone (open symbols) Cepheids with detection. Blue symbols are for Cepheids with upper limit in flux.

Table 1. Comparison of the 70 μm P-L relation with different fitting methods.

Method	Slope	Intercept	Dispersion
Unweighted LSQ	-3.12 ± 0.49	-2.85 ± 0.46	0.39
EM Algorithm	-3.08 ± 0.47	-2.60 ± 0.45	0.49
Buckley-James Method	-3.13 ± 0.48	-2.56	0.39

version of the `ASURV` package does not include the weighted regression, I repeated MAR10 analysis without the weighted fit in order to compare with the results from `ASURV`. The fitted 70 μm P-L relation from the unweighted LSQ regression, the EM algorithm and Buckley-James method is summarized in Table 1. Figure 1 displays the fitted regressions and the observed data. Including the censored data, the result shows that the slopes of the regression are consistent with the one based on detected data only. The intercepts, on the other hand, show an offset between the two approaches.

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