Period-Luminosity Analysis of Cepheid Variables

Towards Cepheid Calibration of Hubble Constant

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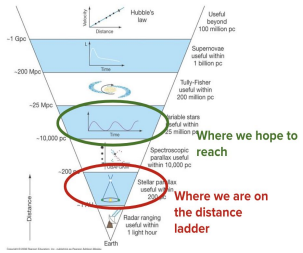
Abstract

We present the development of a period-luminosity relationship model of classical Cepheid stars, based on 275 stars included in Gaia Data Release 2 (GDR 2). We retrieved data, applied quality cuts, and analyzed scatter to obtain the Period-Luminosity relation. For our linear model in log space, Mv = m·log10(P) +b, we obtained parameters m = −2.39 ± 0.06 and b = −0.75 ± 0.04. Assuming this period-luminosity trend is true at wider range of redshift, this result provides us a step in cosmological distance ladder towards the Hubble constant H0.

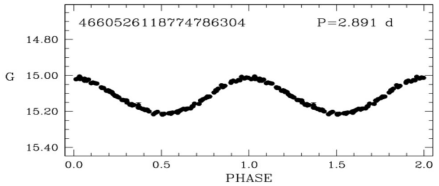
Background and Question

The "Cosmic Distance Ladder"



It is well established that Cepheid variables have a strong correlation between its pulsation period and luminosity (PL relation), which arises from its mass-luminosity relationship. Current understanding of its pulsation mechanism is known as the 'κ-mechanism', which is highly dependent on its evolutionary mass. This property makes Cepheid variables a strong tool to step beyond the limitations of the distance measurement with parallax: a calibration of PL with nearly Cepheids, calibrated with parallax, allows the extrapolation of this relation at larger distances. This allows us to directly measure the distance to galaxies containing Cepheids.

Methods



gaia

Using the Python package *scipy.curvefit*, we performed a fitting of our nominal model to the Gaia datapoints. Here, the luminosity refers to the absolute mean magnitude of Cepheids, and we obtain this from Gaia's accurate parallax measurement and using the distance modulus relation, thereby obtaining a function of distance from absolute and apparent luminosity.

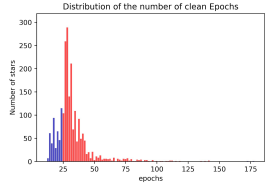
Data

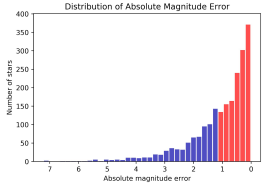
Initially we retrieved data from Gaia for 2139 Cepheids who have non-null period, and calculate the absolute magnitude from the apparent magnitude using the distance modulus relation. We plot the distributions of the period uncertainty, absolute magnitude uncertainty, and the number of clean epochs to filter out stars with poor data or who were not observed often. We make the following cuts to filter out Cepheids with:

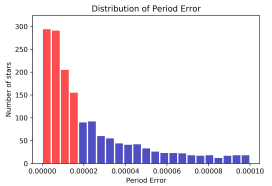
- More than 10^{-4} period error
- More than 1 mag absolute magnitude error
- Less than 25 clean epochs
- More than 30% parallax and flux error

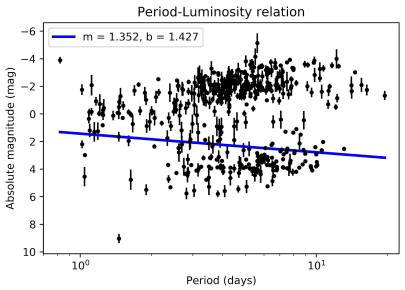
We also applied two cuts from the Lindegren et al. paper. We ended with 275 Cepheid stars and obtained the following model:

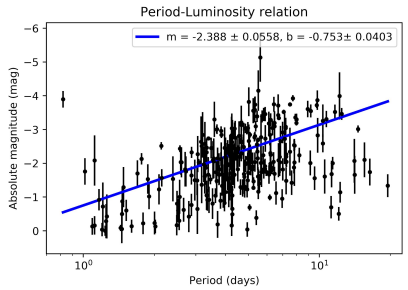
$$M_v = (-2.388 \pm .06)\log_{10}(P) - (0.753 \pm .04)$$











Analysis and Conclusion

To test our model, we used a literature model as our base:

$$M_v = (-2.43 \pm .12)\log_{10}P - 1.62$$

Overall, our slope agrees with this known model. The first thing to note is that this model only includes 10 stars. It is therefore subject to random error and has a larger uncertainty. Using this model as a reference, we note points of improvement for potentially furthering this model. It should be noted that we have dominant systematic error in our model as opposed to random error (we used far more stars than did the reference model).

Our systematic error stems from a couple of areas. The first is that there are multiple types of Cepheid variables, and we should be more stringent and specific about the kind of stars we are using. Furthermore, factors like metallicity and dust reddening phenomena also affect the P-L relationship, and should be taken into account too. Chi-Squared value - 5405 for 275 data points

Future work: Of interest to us in the future is the study of the Hubble constant. The cepheid PL relation is critical to establishing the distances to faraway galaxies, which is critically important to determining the local Hubble constant.

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