Using Gaia DR3 to Calibrate Cepheid Star Luminosity to Give Confidence to the Cosmic Distance Ladder

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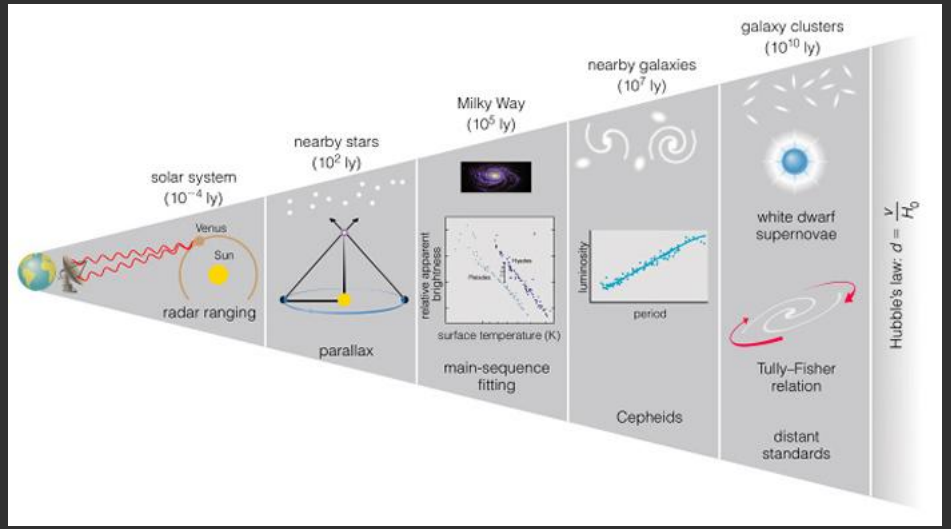
Cosmic Distance Ladder

A series of different methods and objects astronomers employ to observe distant phenomena



Period-Luminosity Relationship

- Developed by Henrietta Leavitt
- Pertains to pulsating variable stars
- States that the time it takes for these stars to pulsate, is directly proportional to their luminosity

Hypothesis

If we use Gaia's Delta Cepheid file from Data Release 3, with the large number of stars, we can identify ways to improve the period-luminosity relation by examining Cepheid stars with a parallax and absolute magnitude with < 0.1 uncertainty. With these improvements, the upper rungs of the Cosmic Distance Ladder will have significantly higher accuracy, providing us with greater confidence in the measured distances.

Collecting Data

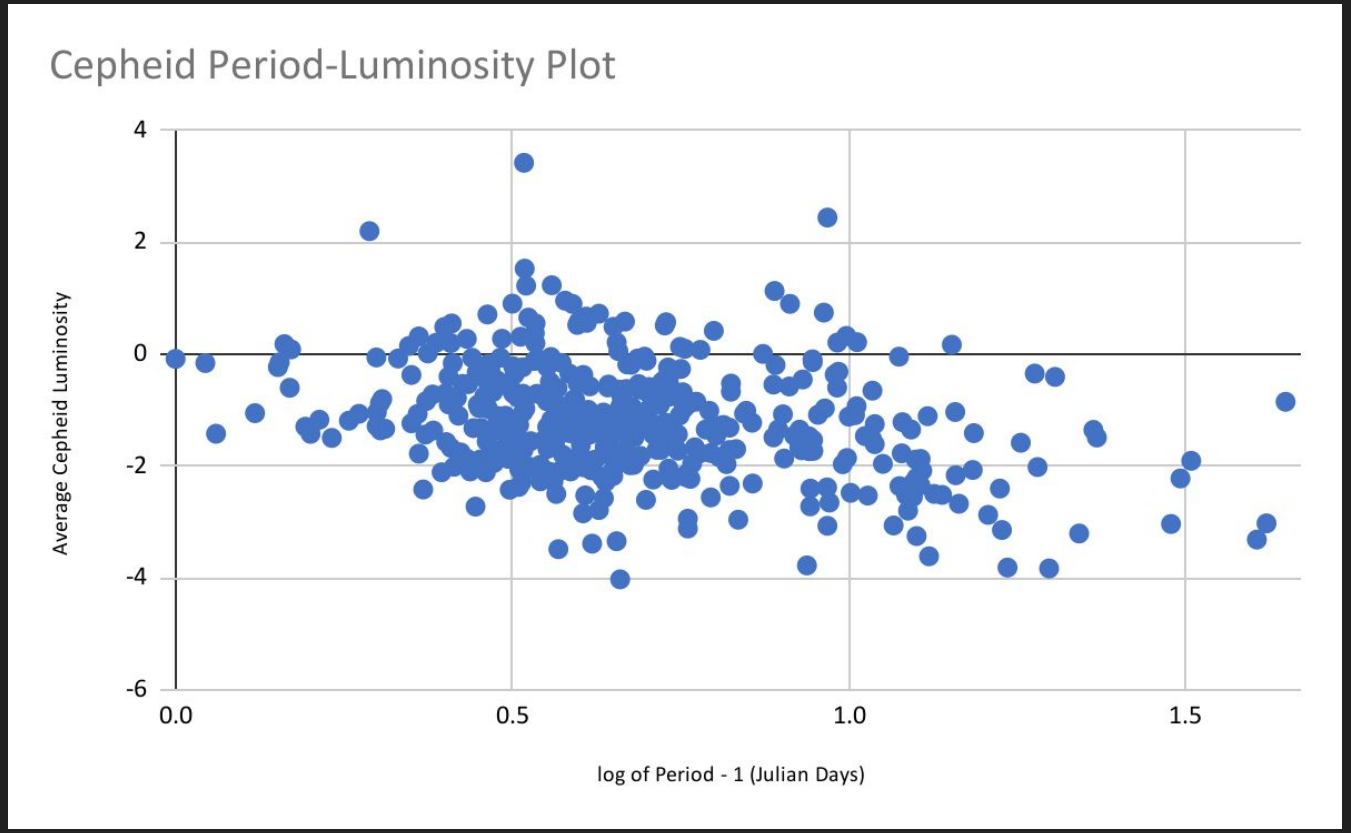
- Gaia Data Release 3 is accessed through the Gaia Archive
- Utilize Advanced (ADQL) search option
- Will come with these columns:
  - source_id, ra, dec, parallax, parallax_error, pf, pf_error, p1_o, p1_o_error, int_average_g, int_average_g_error, int_average_bp, int_average_bp_error, int_average_rp, int_average_rp_error, metallicity, metallicity_error, num_clean_epochs_g, num_clean_epochs_bp, num_clean_epochs_rp, mode_best_classification
- Download from gaiadr3.vari_cepheid

Working With the Data

- Organize data from the mode_best_classification column
  - Only use stars with the FUNDAMENTAL classification
- Remove stars with poorly measured parallax and magnitude
  - Parallax uncertainty must be less than 0.1
- Make table with columns measuring:
  - distance, distance uncertainty, average absolute magnitude in the green band, average absolute magnitude uncertainty in the green band, and log P-1
    - Keep only average absolute magnitude uncertainties that are under 0.1

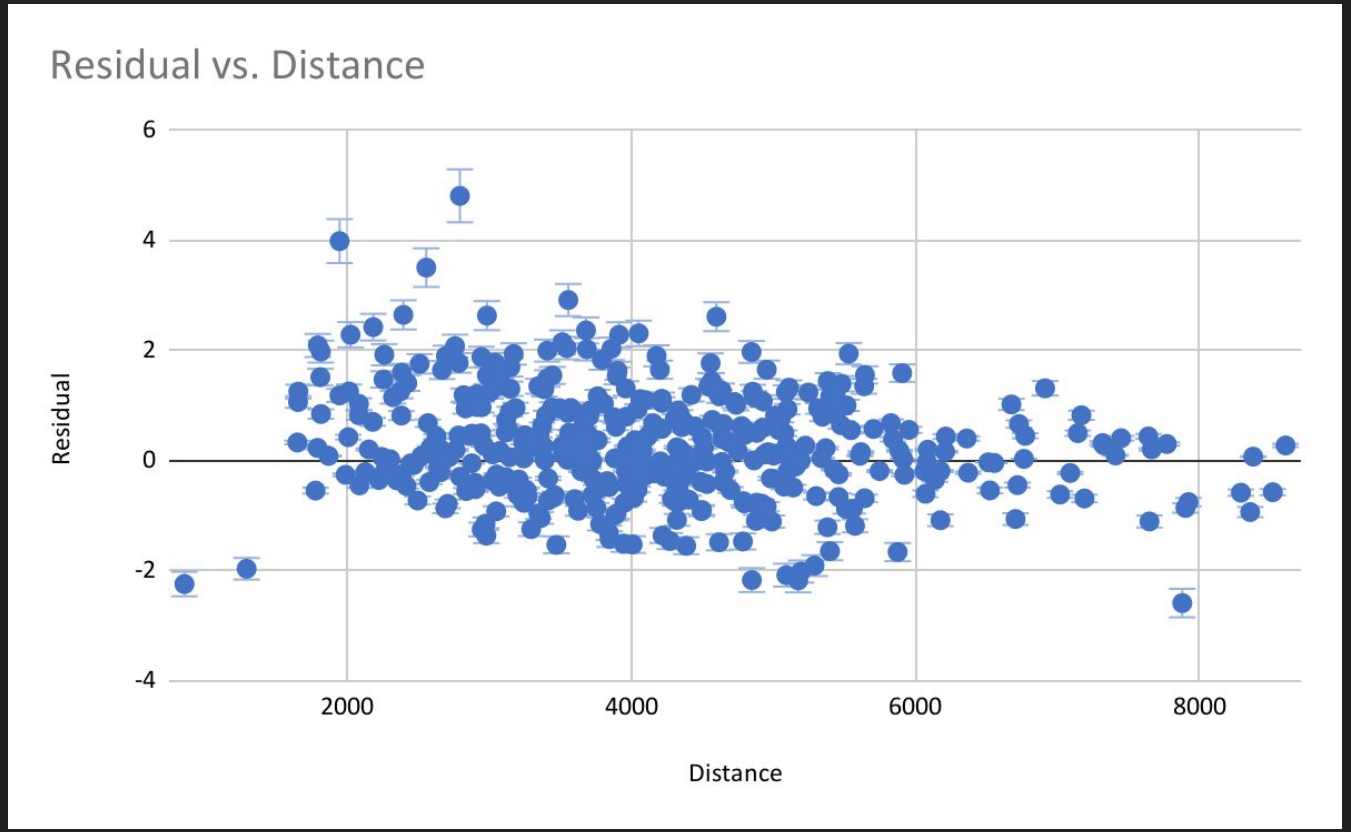
Working With the Data (pt. 2)

- For the filtered stars:
  a. Find average absolute magnitude in the g-band (G)
  b. Find the measured average apparent magnitude (g)
  c. Find the distance (d) using the distance modulus $G = g + 5 - 5 \log(d)$
  d. Make the standard plot of G vs. log(P)-1 where P is the pulsation period of the variable
     i. This should be a linear function with a negative slope and intercept
     ii. The slope and intercept are the calibration constants of interest
- Make a residual plot for the distances measured



log of Period - 1 (x-axis)
Average Cepheid Luminosity (y-axis)

Slope: -0.349; Intercept: -1.209; Slope Uncertainty: 51%



Residual vs. Distance

Analysis

$$a = \frac{1}{\Delta}\begin{vmatrix} \sum y_i & \sum x_i \\ \sum x_i y_i & \sum {x_i}^2 \end{vmatrix} = \frac{1}{\Delta}\left(\sum {x_i}^2 \sum y_i - \sum x_i \sum x_i y_i\right)$$

$$b = \frac{1}{\Delta}\begin{vmatrix} N & \sum y_i \\ \sum x_i & \sum x_i y_i \end{vmatrix} = \frac{1}{\Delta}\left(N\sum x_i y_i - \sum x_i \sum y_i\right)$$

$$\Delta = \begin{vmatrix} N & \sum x_i \\ \sum x_i & \sum {x_i}^2 \end{vmatrix} = N\sum {x_i}^2 - \left(\sum x_i\right)^2$$

$$S_m = S_y\sqrt{\frac{N}{N\sum {x_i}^2 - \left(\sum x_i\right)^2}}$$

a=slope; b=intercept

S_m=Standard Deviation of slope

Using these equations:

- Slope of the Cepheid Period-Luminosity Plot is a= -0.349
- Intercept: b= -1.209
- Standard Deviation of slope: S_m = 0.177
- Slope Uncertainty: S_m/a = 51%

The uncertainty of the slope is large standing at 51%

Setbacks

- Did not account for metallicity
  - Metallicity affects a star’s luminosity
  - Excluded this factor in my previous analysis as Gaia had not measured the metallicity of the stars accurately
- Gaia only measures magnitudes in the g band of the visible light
- Did not account for interstellar extinction
  - Refers to the absorption of light and other forms of electromagnetic radiation by gas and dust that originates from other stars
  - Plausible that dust impeded the accurate measurement of a star's true magnitude

Summary & Conclusions

- Using more data did not necessarily translate to a more accurate period-luminosity relation
- The slope uncertainty is too high to be reliable in these circumstances and did not lead to a better calibration of the Cosmic Distance Ladder
- If setbacks are accounted for, this data can be applied to help the James Webb Space Telescope in detecting distant galaxies as well as any other project that specializes in detection