Data Reduction from Southeastern Association for Research in Astronomy Telescopes and Analysis with Multiple Surveys for Slow Rotating Stars for Gyrochronology

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Abstract

Gyrochronology, the method of estimating the ages of stars from their rotation rate, relies on precise measurements of minute changes in brightness. In addition, stars with long rotation periods require longer time coverage than is usually provided by single-mission space-based observations. To improve the detectability of rotation periods longer than tens of days, we supplemented data from space-based missions such as NASA's Kepler, K2 and Transiting Exoplanetary Survey Satellite (TESS), ESA's Global Astrometric Interferometer for Astrophysics (GAIA) with ground-based data from the Southeastern Association for Research in Astronomy (SARA) telescopes, enhancing accuracy. We used the 0.9 m telescope at the Kitt Peak National Observatory, the 1.0 m Jacobus Kapteyn Telescope at the Observatorio del Roque de los Muchachos in the Canary Islands, and the 0.6 m telescope in Cerro Tololo to take data over several nights. AstroImageJ (AIJ) was employed to conduct multi-aperture photometry on the SARA data, to help fill gaps in time coverage provided by space-based missions. In this poster, we outline the reduction procedures applied to the SARA data and present some preliminary results of our efforts to combine ground- and space-based data.

Light Curves

- The light curve analysis provides crucial insights into the star's behavior, including the magnitude of its brightest and dimmest flux.
- Additionally, the regularity of the star's spin, as revealed by the light curve, is a key factor in understanding its characteristics.
- Determining the rotational speed of the star enables the application of various gyrochronological models, which in turn aids in estimating the star's age.
- Wide-binary systems are utilized to enhance the accuracy of age predictions, ensuring consistency between the ages estimated for both stars in the binary system.
- Three distinct pipelines—Lomb-Scargle, Wavelet, and Auto-correlation—are employed to analyze the data and derive the star's age.
- The team at FGCU has developed a comprehensive pipeline capable of running data through all three simulations, facilitating a thorough analysis of the star's properties and age determination. See Figure 1 and Figure 2.

SARA Observing

- The SARA Consortium provides us with access to several telescopes, which we used three of the four:
  - 0.9 m telescope at the Kitt Peak National Observatory,
  - 1.0 m Jacobus Kapteyn Telescope at the Observatorio del Roque de los Muchachos
  - 0.6 m telescope in Cerro Tololo
- Our process begins by targeting stars previously observed by various missions.
- Once data for the night is collected, it's aligned and multi-aperture photometry is performed. This data from is then put into an excel sheet to be analyzed
- After alignment and photometry, the data is normalized based on the average flux for each night, allowing for slight variations between them.
- This integrated data supplements previous collections from different missions, helping us bridge any gaps and confirm expected periodicity.
- Deviations from our models prompt further examination to verify their efficiency for slow-rotating stars. Matching variations validate the models and invite additional rigorous testing with slower stars. See Figure3 and Figure 4.

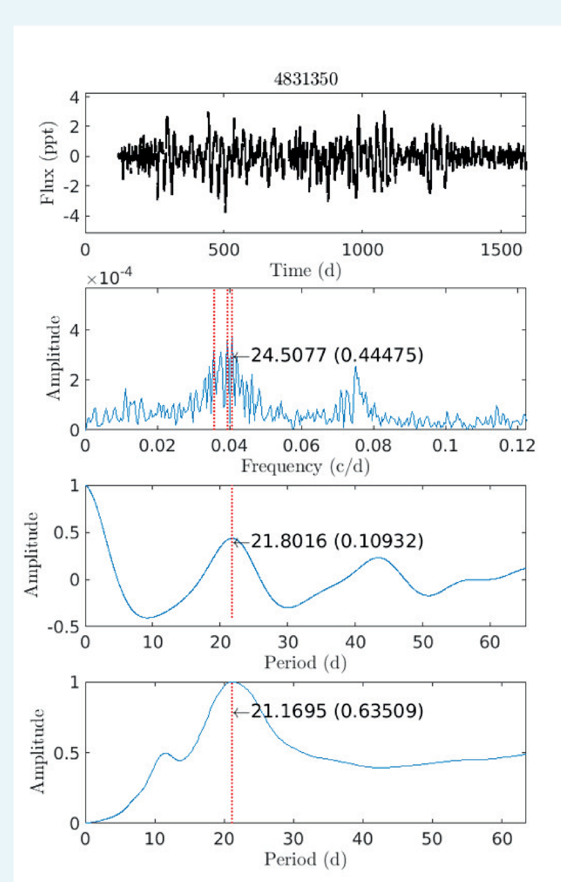

Figure 1: Lomb-Scargle output for TIC 4831350

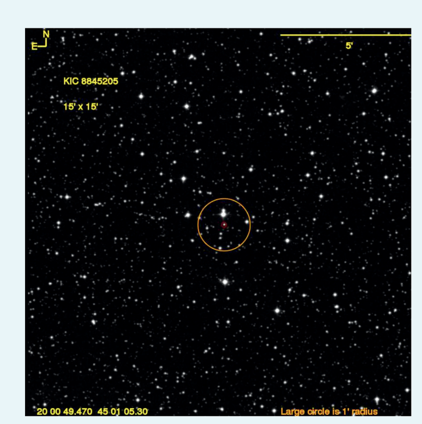

Figure 2: Finding Chart for TIC 4831350

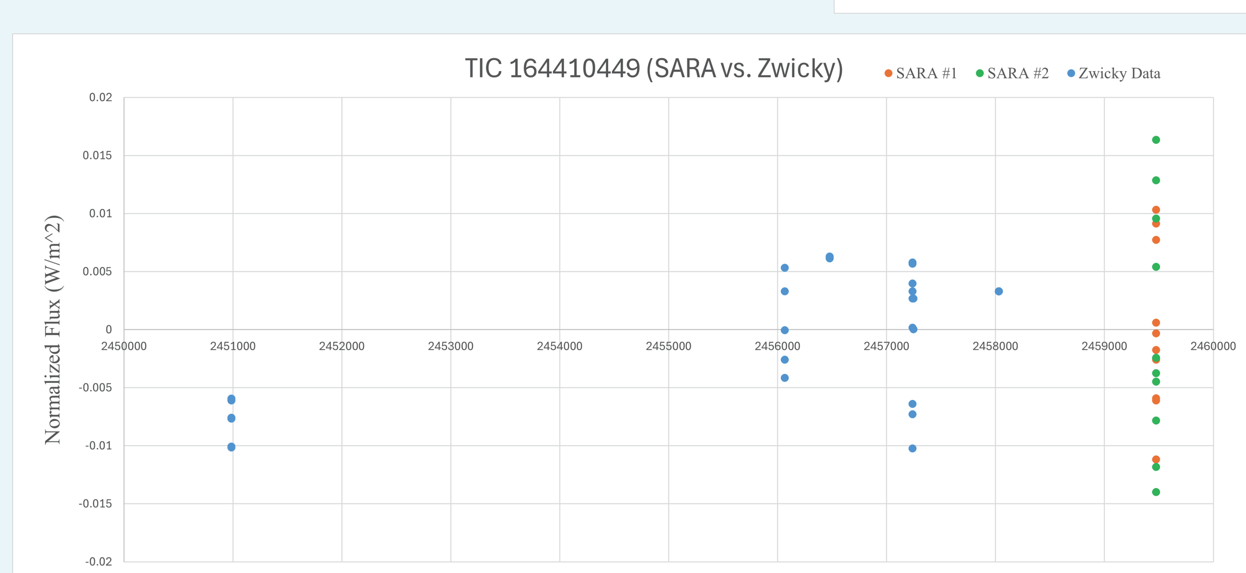

Figure 4: Shows the comparison of light curves from SARA and Zwicky data

GAIA, Zwicky, TESS, and Kepler

- There is a large variety of surveys to choose from. We decided to base a majority of our calculations off of Kepler, as it was one of the most accurate and longest missions out of our options.
- Only some stars are observed by multiple surveys, so they have to be cross examined to ensure that multiple missions have the data available. For example, GAIA has only released some of the data that it has observed to the public.
- While trying to match the calculations from Kepler, we can test the other surveys. We know that if the results are similar to Kepler's light curve, then it is more trustworthy.
- We can base the accuracy of the estimations for stars that rotate very slowly on the new data. From Kepler we can estimate the rotation period, then we can verify it with data from a different BJD.
- SARA data is collected over the period of very few nights, which means that it alone is unable to determine the period of the rotation. However, it acts as a good supplemental material when added with the other missions.
- Figure 3 and Figure 4 are graphs showing a variety of missions combined. The wavelength is regular enough as the target star has not been observed to have any behaviors that could affect that.
  - The curve is not a perfect sinusoidal function and can have different, unique behavior. See Figure 5.
- SARA data is used within the gaps of dates between the missions for stars that have a more complex behavior.
- Zwicky is a unique survey as it is the only one we are comparing our ground-based SARA data with that is not space-based.
- The survey is widely used for light curves, but is noted to not be accurate as space-based surveys. It is still extremely useful.

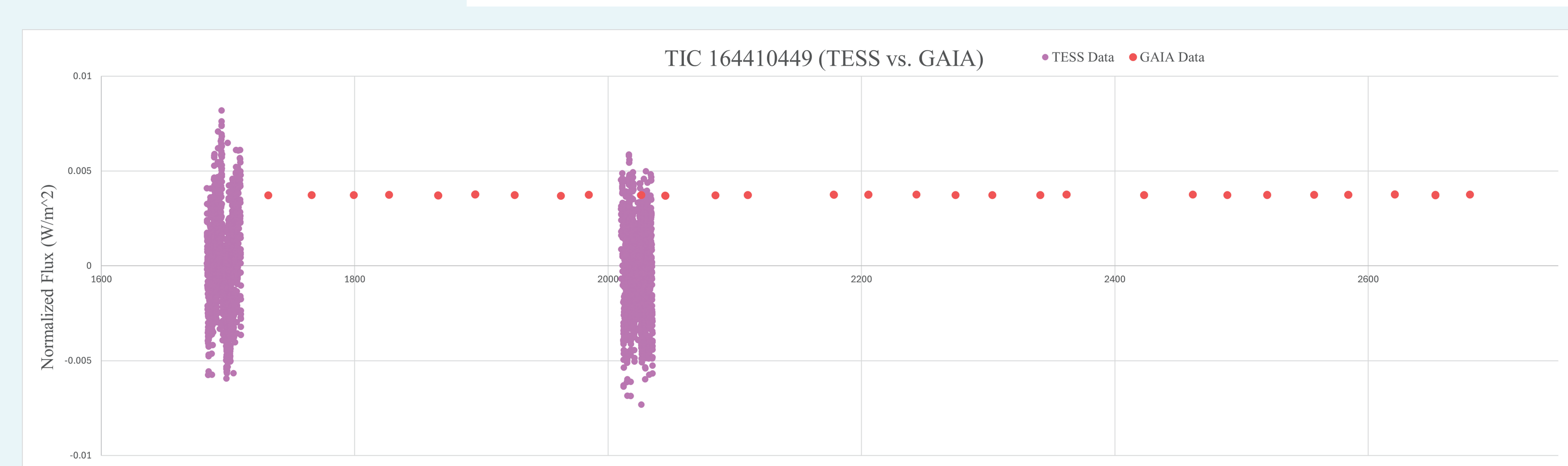

Figure 3: Shows the caparison of light curves from TESS and GAIA

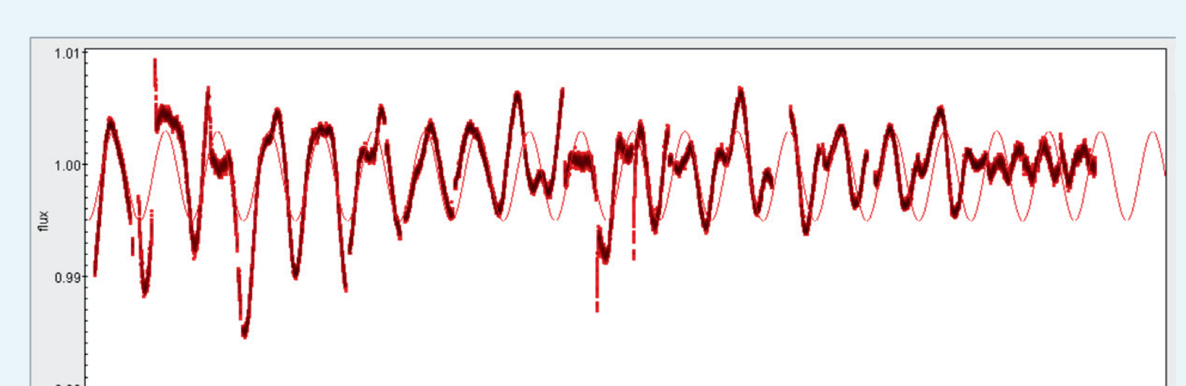

Figure 5: TIC 8143903: Double Sine Wave imposed over the light curve data of the Kepler Data, calculated with Lomb-Scargle function.

Results and Future Work

- The results thus far are promising, as the estimated waves match different missions than the ones they are calculated with.
- This can be used to further add confidence to the estimations of stars that have slower rotation rates.
- The amount of stars with slow rotations in the overall gyrochrone is extremely small, which adds doubt to the current gyrochronological estimations of when gyrochronology applies. By finding more stars with slow rotation rates we can compare the results to their wide binary pairs, which allows us to find where gyrochronology limits exist.
- SARA data adds more points and can be used to check exact points of interest.
  - When the light curve peaks.
  - When there are unique spikes and behaviors within the light curves.
  - When the light curve is at a minimum.
- Moving forward, collecting more data from SARA will allow for more accurate gyrochronoligcal estimations from the light curves of slow rotating stars.
- An increase in the data pool for these stars that are within wide binaries will add overall confidence to the understanding.
- Future work requires we document a list of known slow rotating stars to target specifically when observing with SARA telescopes. We then can preform multi-aperture photometry and gather more data points at unique points in the light curve.
- Continued work includes comparing the outputs from a variety of pipelines. We are currently focusing on the outputs from a Lomb-Scargle pipeline via Period04 to calculate the most likely period.
  - Stars that differ from their wide-binary pair with the pipelines show us that that pipeline doesn't apply properly to slow rotating stars and a different one should be used.
  - Most commonly used is Lomb-Scargle, however no large-scale studies have been conducted on which pipeline would be the most accurate in this scenario.

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