Detecting Stellar Rotation with the Synchrosqueezing Wavelet Transform

Cassandra McGinley[1], Mariel Lares[1], Derek Buzasi[2], Terry D. Oswalt[1]
[1]Dept. Physical Sciences, Embry-Riddle Aeronautical University, Daytona Beach, Florida USA
[2]Dept. Chemistry & Physics, Florida Gulf Coast University, Fort Myers, Florida USA
mcginlec@my.erau.edu, laresm@erau.edu, buzasi@fgcu.edu, terry.oswalt@erau.edu,

ABSTRACT

The main goal of Gyrochronology is to determine stellar ages by understanding how stars slow down in their rotation as they age. In order to achieve such a goal, rotation periods must be determined with high precision. Various tools are available for determining stellar rotation periods, such as the Auto-Correlation Function (ACF), Lomb-Scargle periodograms, or Classical Wavelet analysis (CWT). However, each method has strengths and weaknesses when applied to determining stellar rotation rates. One weakness of Classical Wavelet analysis is the relatively low precision with which periods are determined. A new algorithm for wavelet analysis, called Synchrosqueezing Wavelet Transform (SWT), claims to deliver more precise periods than the classical analysis. This poster presents the results of computing classical and SWT wavelet analysis rotation periods for a sample of 3912 stars that are components of wide binary systems. So far, the SWT results show a significant improvement in the precision of rotational periods, as expected. The SWT algorithm is likely to become part of the Gyrochronology team's pipeline for stellar rotation period determinations.

Background

- Various methods can be used to find the period of stellar rotation, such as Classical Wavelet Transformation (CWT), Lomb-Scargle Periodograms (LS), or Autocorrelation Functions (ACF)
- CWT allows period detection at high frequencies with short time frames and low frequencies with long time frames [1]
- As the frequency range rises, the resolution of the frequency decreases [1]
- The Synchrosqueezing Wavelet Transform (SWT) is the proposed algorithm that intends to reduce the frequency error of CWT outputs [2]
- SWT takes CWT outputs and "squeezes" the resolution of the frequency to create a more precise interval of the probable frequency [4]
- SWT reduces the noise of a signal through its algorithm [1]

Results from Other Researchers

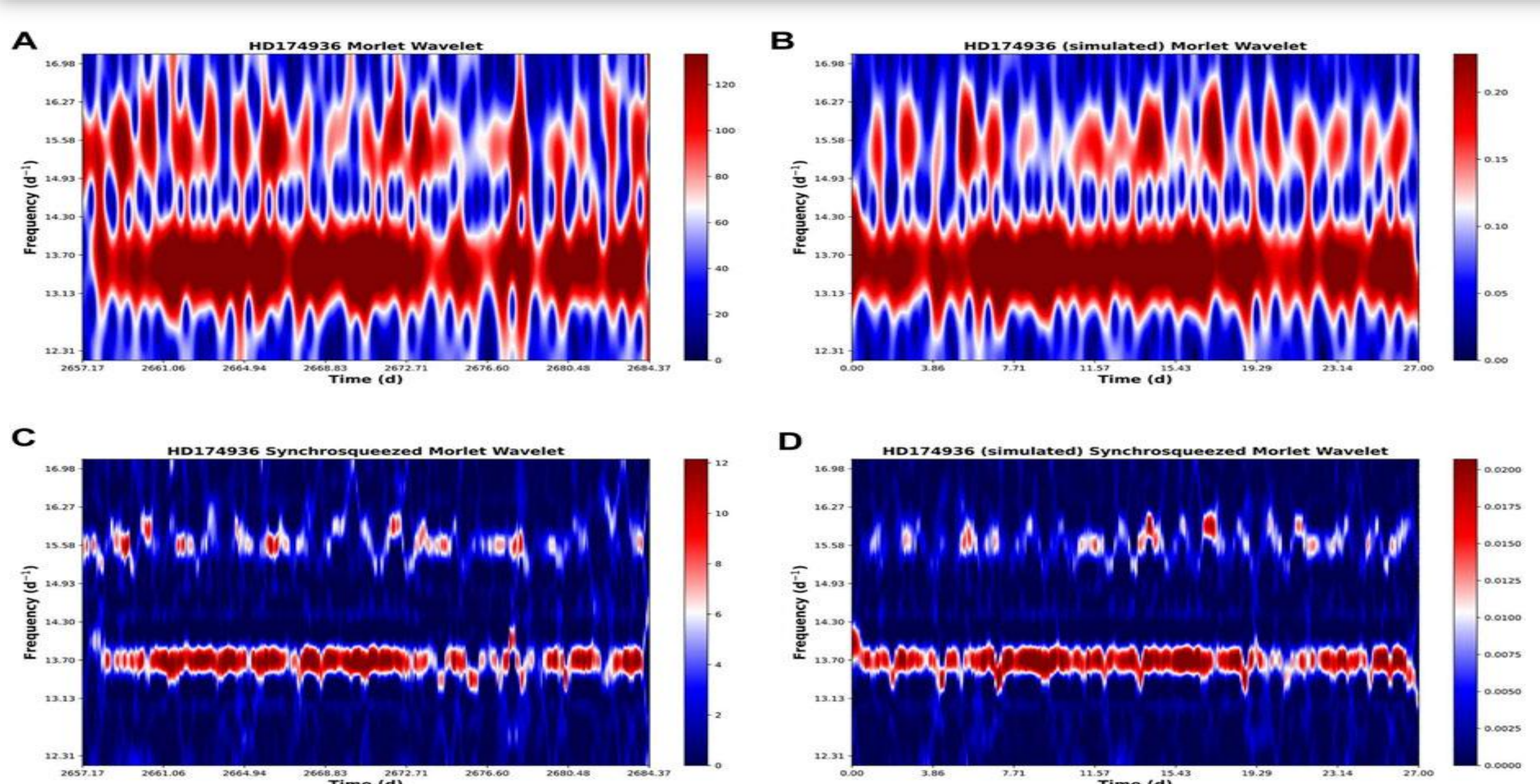

Fig. 1- These four plots were created by researchers from Granada, Spain, who compared CWT and SWT when studying pulsations in two Delta Scuti stars, HD 174936 and HD 174966. In the bottom row, SWT seems to have increased the precision of the samples' frequency signals [1].

Our CWT and SWT Figure Computations

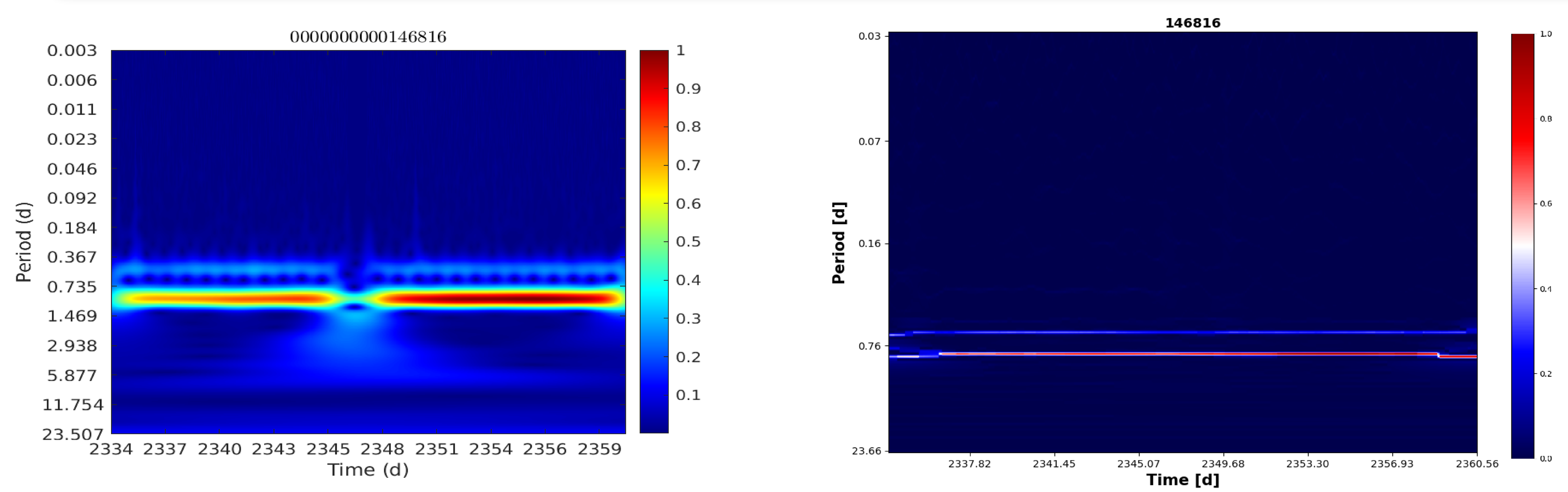

Fig. 2- The two images above show the results of CWT and SWT on the same sample, Tess-146816. On the left is the Classically Transformed wavelet, and on the right is the Synchrosqueezed wavelet. A significant decrease in the range of the period can be seen from the CWT to SWT plots. Specifically, there is a smaller range of error in the second plot using SWT. SWT is completed by estimating the instantaneous frequency at each point, and then reassigning the frequency gathered into bins [4]. This then allows to create a defined wavelet transform with a much more precise line [3].

Next Steps

- Interpolating or rebinning all the light curves of our sample to compute the SWT since its algorithm requires the observations to be equally spaced
- Quantify the improvement in rotation period determination by looking at whether pairs of wide binaries better track gyrochrones

References

[1] A. Ramón-Ballesta, J. Pascual-Granado, & Garrido, R. (2022). Time-frequency analysis of HD 174936 and HD 174966 using the synchrosqueezed wavelet transform. *Frontiers in Astronomy and Space Sciences*, *9*. https://doi.org/10.3389/fspas.2022.948979

[2] Daubechies, I., Lu, J., & Wu, H.-T. (2011). Synchrosqueezed wavelet transforms: An empirical mode decomposition-like tool. *Applied and Computational Harmonic Analysis*, *30*(2), 243–261. https://doi.org/10.1016/j.acha.2010.08.002

[3] Jiang, Q., Prater-Bennette, A., Suter, B. W., & Zeyani, A. (2022). Instantaneous Frequency-Embedded Synchrosqueezing Transform for. Signal Separation. *Frontiers in Applied Mathematics and Statistics*, *8*. https://doi.org/10.3389/fams.2022.830530

[4] *Wavelet Synchrosqueezing - MATLAB & Simulink*. (n.d.). Www.mathworks.com. Retrieved March 31, 2024, from https://www.mathworks.com/help/wavelet/gs/wavelet-synchrosqueezing.html#

Acknowledgements

Support from NSF grants AST-1910396, AST-2108975 and NASA grants 80NSSC22K0622, 80NSSC21K0245, and NNX16AB76G is gratefully acknowledged.