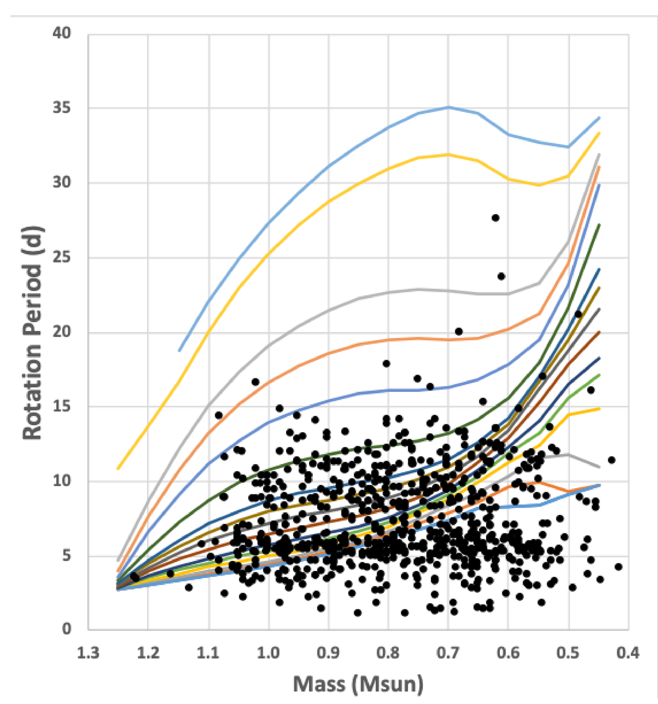
Testing the Gyrochronology Paradigm Using Wide Coeval Binary Stars

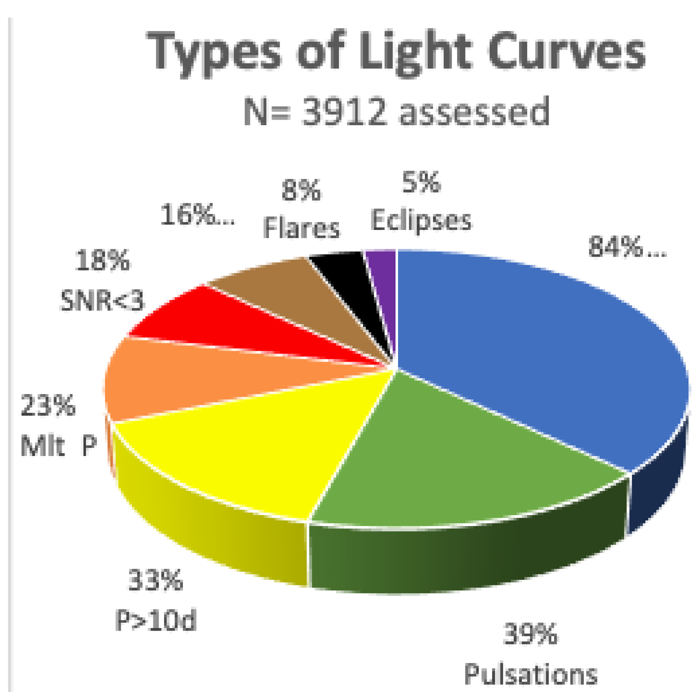
[1]Krystian Confeiteiro, [1]Petar Grigorov, [1]Carina Shanahan, [1]Ahnika Gee, [1]Sam Lutzel, [1]Sima Vaidya, [1]Terry Oswalt, [2]Derek Buzasi

[1]Embry-Riddle Aeronautical University, [2]Florida Gulf University

What is Gyrochronology?

- Gyrochronology is the empirical relation between a star's rotation rate and its age. For stars on the main sequence (MS stars) of spectral type F through M, gyrochronology may be an accurate way to measure stellar ages for stars roughly 0.6 to 1.0 solar masses.
- Components of wide non-interacting binaries are coeval, meaning that the ages indicated by rotation rate or other methods are identical within observational and/or model uncertainties.





The 731 highest-quality period determinations from the L-S pipeline, were compared to the gyro models of Spada & Lanzafame (2020). In accordance with Avallone et al. (2022), few periods longer than ~14 days are detectable in a single TESS cycle. Also in this plot is an apparent excess of periods around 5-6 days.

The initial visual inspection of 2573 of our project's light curves revealed all but 731 (28%) have problems such as contamination of the target or sky masks that may affect period determinations. These assessments were used as a training set for the CNN.

Fig. 3

Light Curves

1. The top panel is the raw light curve for a typical TESS target star. Usually, several sectors are separately normalized and stitched together (note the gap between the two sections of the top panel in the figure) though in Fig. 1, we have the downlink gap for a single sector.
2. The second panel shows the amplitude-frequency spectrum of the light curve from the Lomb-Scargle pipeline. For most stars with signals dominated by rotation, the peak will be all the way on the left somewhere, since those periods are typically longer than a day.
3. The third panel is the same data as the second panel, plotted on a logarithmic scale, which makes period peaks longer than a day more visible.
4. The fourth panel is the light curve phased using the highest-amplitude peak. The corresponding period is noted on the x-axis. Overlaid in red is the same data, binned to the 0.01 phase to make it easier to pick out any trend(s) from the noise.
5. There are two images in the bottom panel. On the left is the original "postage stamp" TESS field for the target star. On the right is shown the aperture masks used to produce its light curve. Here the yellow pixels are the target star's aperture, the light blue areas were used to estimate the background, and the darker blue pixels were unused.

Machine Learning

- Machine learning is a subclass of Artificial Intelligence (AI) that can be trained to classify images.
- Deep learning is another subset of AI that goes beyond ordinary classification models and is modeled after how our brains function using artificial neurons, convolution layers, and activation functions (like ReLU and tanh). Image classification is often used to determine if an object (or objects) of interest is included in an image.
- We utilized this aspect of machine learning to determine if the TESS postage stamps (raw images) were good enough to be used in our tests of gyrochronology models.
- We adopted a Convolutional Neural Network (CNN) approach, which uses convolution layers to reduce the dimensions of the input pictures and effectively classify them. For both the machine learning and neural network, a class size of two (good or bad), and a dataset of size 2554 was used.
- Those with specific problems were marked for "redo," and sent back for more careful extractions. An image set of 2554 stars were chosen, which was sorted into 20 and 80 percent, respectively, for training and testing, respectively.
- The highest accuracy achieved by the CNN was 82% in epoch 60 out of the designated 100. This means that the CNN model accurately predicted the classification made by the human who inspected the image 4 out of every 5 times.

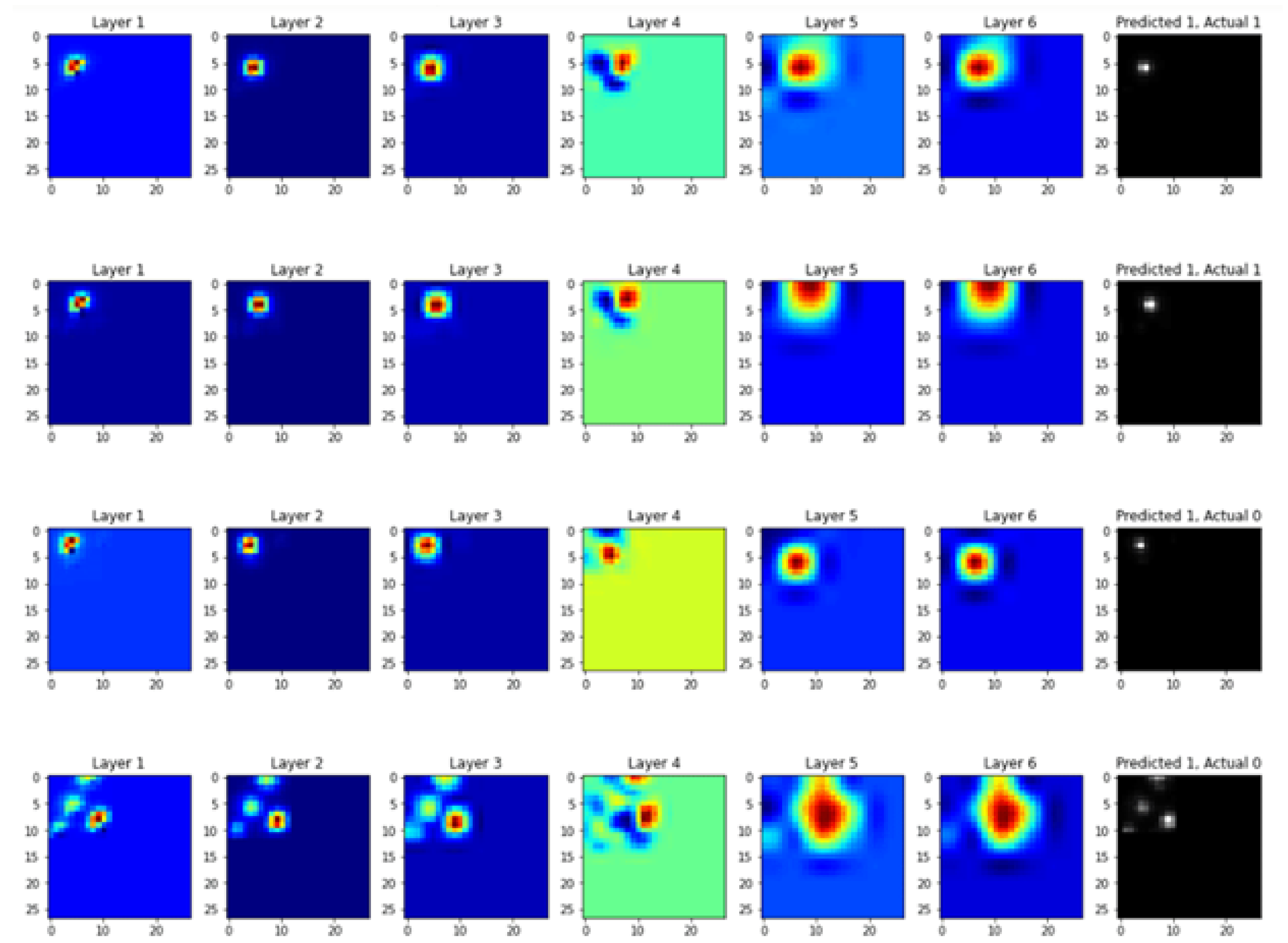


Fig. 2: Visualization using GradCAM

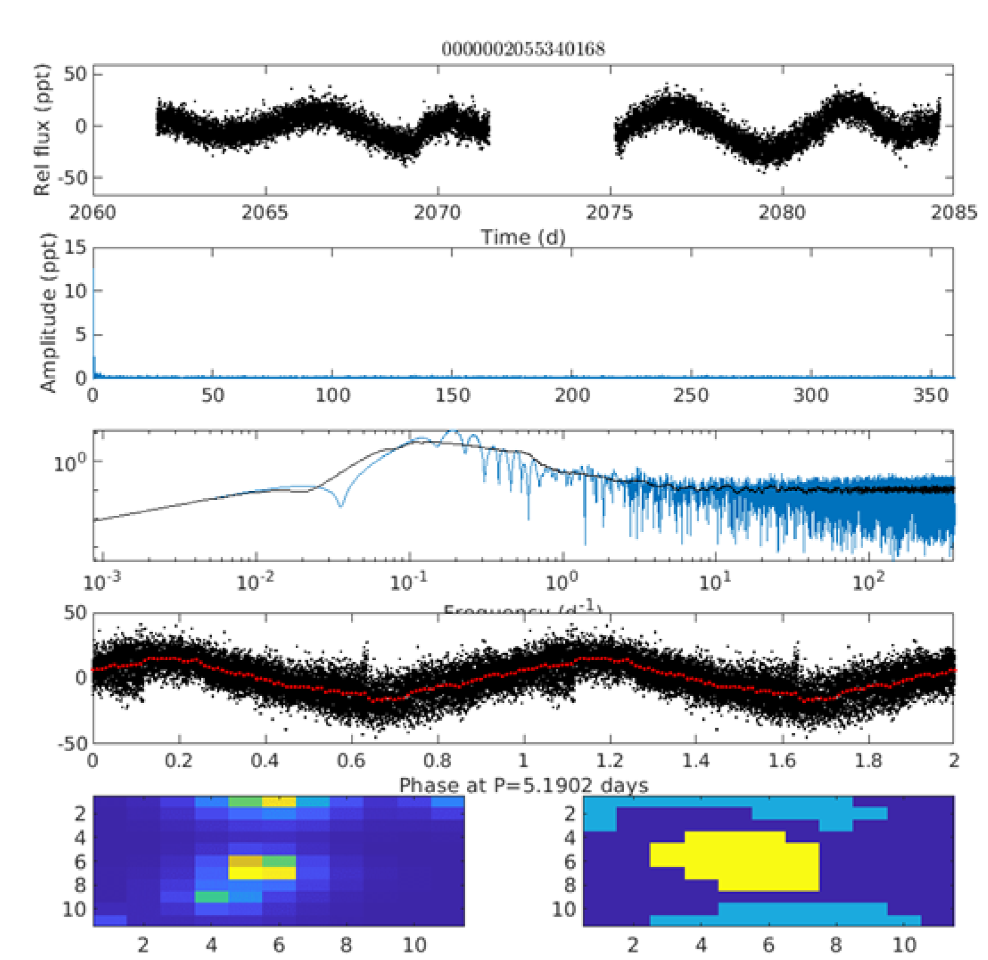


Fig. 1: Example of a "good" light curve

Conclusions

- The output of any extraction pipeline needs to be carefully assessed.
- TESS does not probe rotation rates beyond ~14 days.
- Prospective stellar gyrochronology targets must be well vetted to eliminate blends and other problem objects, CNN algorithms can do this vetting using a training set based on visual inspection of a large enough learning sample.

Acknowledgements

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

References

1. Spada, F., Lanzafame, A. 2020, "Competing Effect of Wind Braking and Interior Coupling in the Rotational Evolution of Solar-Like Stars," A&A 363, A76
2. Géron, Aurélien. (2023). Hands-on Machine Learning with Scikit-Learn, Keras, and Tensorflow: Concepts, tools, and Techniques to Build Intelligent Systems. O'Reilly.
3. Proposal for grants NASA and NSF grants NSF AST1910396 and NASA 80NSSC22K0622
4. van Saders, J. (n.d.). Research. Jennifer van Saders. Retrieved December 30, 2022, from https://home.ifa.hawaii.edu/users/jvsaders/#research
5. Ellis A. Avallone et al 2022 ApJ 930 7

Discovery Day 2023 - Gyrochronology Contact Form