Determining Rotation Periods of Kepler Stars in Order to Measure Stellar Inclination

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The purpose of this project was to determine the stellar inclination $i_*$ of various Kepler stars. The way this was accomplished was by analyzing photometric data of these stars and determining their rotation periods. Combining this data with data from analyzing these stars with asteroseismology would allow us to more precisely determine $i_*$. 

I. INTRODUCTION

Though one of the more widely accepted hypotheses of planetary system formation assumes that the planetary disk rotates perpendicular to the rotational axis of the central star, there have been observations of planetary systems in which the rotational axis of the central star has been shifted by some angle of inclination $i_*$ parallel to the observer’s line of sight and by some angle of inclination $\lambda$ perpendicular to the observer’s line of sight. There are many hypotheses as to why the rotational axis of the central star becomes shifted, however the purpose of this project was to determine the stellar inclination $i_*$. Since $\lambda$ is easily determined from spectroscopic data, we are left to the task of finding $i_*$. 

II. BACKGROUND

A. Asteroseismology

Asteroseismology is the study of stellar oscillations. Asteroseismology uses photometric data, in the form of lightcurves, to determine the value of $\frac{1}{P_{\text{rot}}} \sin(i_*)$ precisely where $P_{\text{rot}}$ is the rotation period of the star. Although asteroseismology can determine
FIG. 1: Plot for Kepler 5866724. This plot shows that the most likely stellar inclination corresponds to a rotation period of about 8 days.

this value, this method cannot measure $P_{rot}$ and $\sin(i_*)$ individually as precisely. Since the ultimate goal of this project is to determine accurate values of $i_*$, we must measure accurate values of $P_{rot}$. Figure 1 is derived from asteroseismology data. This plot shows the most likely stellar inclination of a star, in degrees. However, because the plot only shows the likely distribution, an accurate value of $i_*$ and $P_{rot}$ individually cannot be calculated. Therefore, for this project we had to come up with a method, independent from asteroseismology, to determine $P_{rot}$. After doing this we must then compare the independently determined $P_{rot}$ with the $P_{rot}$ derived from asteroseismology. By doing this, we can reduce the likely distribution of the stellar inclination and determine a more accurate value for $i_*$. 
B. Determining Rotation Period from Photometric Data

There are a couple different ways to determine the rotation period of a star from just photometric data. We decided to determine the rotation period by creating a Lomb-Scargle periodogram of the photometric data. We used various python packages from PYKE in order to create these periodograms. We then fitted these periodograms with a Gaussian fit, with the median value of the Gaussian fit being the most probably period of the star.

III. DATA ANALYSIS

A. Lomb-Scargle Periodograms

Figure 2 is a typical example of the lightcurve of a Kepler star. Using the time and flux data of these lightcurves, we created periodograms for 94 stars. This set of stars includes both planet-host and planet-less stars. Figure 3 is an example of a periodogram that provides us with a good estimate for the period of the star. The median and median error are that of the Gaussian fit. We also included the peak value and the full width half max of the peak. Some of the 94 periodograms are not as useful to us due to data missing from the lightcurve data or very short periods of observation. We divided these 94 periodograms into three categories, bad, good, and maybe. Bad periodograms give us no useful information. There were 28 periodograms in this category. Good periodograms are the most reliable ones. There were 28 periodograms in this category as well. The maybe category includes periodograms that could have accurate periods but it is not extremely evident if they do. There were 38 periodograms in this category. Due to photometric variation, however, the estimated period may not be very accurate. In order to test the accuracy of this period, we have to analyze the lightcurve by eye as well and determine the accuracy of the period.

B. Folded Lightcurves

In order to reaffirm the reading given by the Gaussian fit, we folded the lightcurves of the Kepler stars by the period given by the Gaussian fit and analyzed these folded lightcurves by eye to determine how accurate the estimated period is. For Kepler 5866724, the estimated period is about 8 days. As such, 8 pages of 20 period segments each and one page of 18 period segments were created. The sharp dips in this folded lightcurve are due to a transiting planet. When determining the periodicity of the star, we must disregard these dips since the orbital period of the planet is most likely not the same frequency.
FIG. 2: The lightcurve for Kepler 5866724. This is an example of the lightcurve for a typical kepler star. The y-axis indicates relative flux while the x-axis indicates the day observed.

FIG. 3: The periodogram for Kepler 5866724. The red line is the Gaussian fit to the periodogram. The median and median error are that of the Gaussian fit. The x-days displays the possible periods for this star. The y-axis displays the likeliness of a particular period being the true period.
FIG. 5: All of folded periods for Kepler 5866724. The y-axis is the relative flux of each period segment while the x-axis is the number of days.

as the rotation period of the star. By finding similar features between many different pairs of adjacent period segments, we can determine that the estimated period is indeed the true period.

IV. RESULTS

Using data from the asteroseismology-derived most likely periods and the periodogram derived periods, this plot was created. On this plot, there are three dashed orange lines. The top line represents $y=2x$, 

FIG. 6: Asteroseismology Period vs. Periodogram Period.

the middle line represents $y=x$, and the bottom line represents $x=2y$. The reason for these three dashed lines is to help visualize how many of the x-axis periods are double, the same, or half the value of the y-axis periods. If a period on the x-axis is double that of the period on the y-axis, we can interpret that as one of the axes accidentally marking double the period as the true period. This is somewhat likely to happen since, due to being periodic, the lightcurve repeats itself after each period. This plot shows the asteroseismologically derived periods on the y-axis versus the periods determined the Lomb-Scargle periodograms on the x-axis. It seems as if the majority of the points are within the $y=2x$ and $x=2y$ lines with the majority of those points being on the $y=x$ line. This means that the periodogram-derived periods match up pretty well with the periods derived from asteroseismology. This is great because that means we can reduce the error on the asteroseismology data which will help us determine a more accurate value for $i_*$.!
V. REFERENCES

C. Hayashi, 1981