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In Search of Exoplanets

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ABSTRACT Using data archives containing radial-velocity and light-intensity information for stars, the DePaul Astrophysics Working Group created MATLAB code to read and analyze the data in hopes of detecting extrasolar planets. The code was able to successfully create graphs and obtain orbital periods for potential planets which matched published results. Additional tests were then researched to be used in the future as a way to confirm new planets.

1. INTRODUCTION

Over the course of human history, people have gazed into the night sky, wondering what was up there. It is only through recent scientific advancements, within the last thirty years, that people now have the tools to actively search for worlds beyond the Sun, as far as millions of light years away.

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This paper describes an astrophysics research project based on the two main methods that are currently employed in the search for extrasolar planets. The Radial Method, is an indirect method that looks at the wobble of a star caused by an orbiting planet. The more direct Transit Method detects the dimming of a star's light output as a planet passes in front of the star.

Until the launch of the Kepler spacecraft in 2009, the Radial Method was the primary method for finding planets outside of the solar system. For example, it was used in the first discovery of a planet orbiting an ordinary star more than twenty years ago [1].

To understand how this works, con- sider a planetary system with a star and its or- biting planets, moving around their common center of mass in elliptical orbits. It is be- cause planets are too faint to detect directly that their existence has to be inferred from the motion of the star. This can be difficult because the masses of stars are normally much larger than those of their planets, and thus their orbits are much smaller. However, unless the inclination of the orbit relative to the line of sight from an observer on Earth is exactly 90 degrees, the star travels either toward or away from the observer during different parts of its orbit. When a star is moving towards Earth the observed wavelength of the light becomes shorter than its at-rest wavelength. This is referred to as a blueshift. On the other hand, when the star is moving away from the observer, the observed wavelength becomes longer, or red-shifted. These periodic wavelength shifts of stars can be detected by monitoring them over time periods ranging from days to years. The rate of motion, outward or away from the observer, is called radial velocity. Radial velocity is negative if the star is moving toward the observer, and positive if it is moving away. Planets with large masses, small orbits, and small inclination angles are easiest to detect because they cause the largest radial velocities of their stars.

After the launch of the Kepler space- craft, the Transit Method has become the most popular method for detecting extrasolar planets. For a small fraction of planetary systems the orbital inclinations are so small that the planets move between star and the observer for parts of their orbits. The Transit Method [2] is based on detecting the slight periodic dimming of stars during such transits as some starlight is blocked by the planets. Planets that have large diameters relative to their stars are easiest to detect as they cause larger "dips" in brightness. Bigger planets block more light when they pass in front of stars making them easier to detect. The same is true for planets that are closer to us than the star, as they appear larger and block more light. The Transit Method is used by NASA's Kepler spacecraft [3], which is responsible for detecting the vast majority of currently known planets.

2. METHODS

2.1. Radial Velocity Method.

This research has made use of the Exoplanet Orbit Database and the Exoplanet Data Explorer at exoplanets.org [4]. The website is an archive that has thousands of published data sets taken from observatories all over the world. One can search for any star and find radial velocity information about it, as well as information about transit and other methods. For the purpose of this portion of our research, only the radial velocity data was used.

The extracted data contained each Julian date and associated radial velocity measurement over a period of time for several stars. For some stars, multiple data sets were combined to obtain longer time periods for our analysis. However, we did not use data sets if they duplicated other data in our sample or if the timespan was very short. Fig. 1 shows a typical radial velocity plot for HD (Henry Draper) 164922, one of the stars in our sample. Because orbital motion is periodic, our general strategy was to identify periodic wavelength shifts in these data. The common way to detect periodicities in a signal is by using Fourier analysis. However, standard Fourier techniques rely on the data being sampled uniformly in time. Note that the time intervals between the measured radial velocities in Fig. 1 are not uniform, thus requiring the use of a Lomb-Scargle periodogram [5] instead of simple Fourier analysis to compute the frequency spectrum. The Lomb-Scargle periodogram can determine frequencies of irregularly spaced data by estimating the frequency through probability rules of sinusoidal functions.

In order to obtain other physical parameters, such as planetary and stellar masses

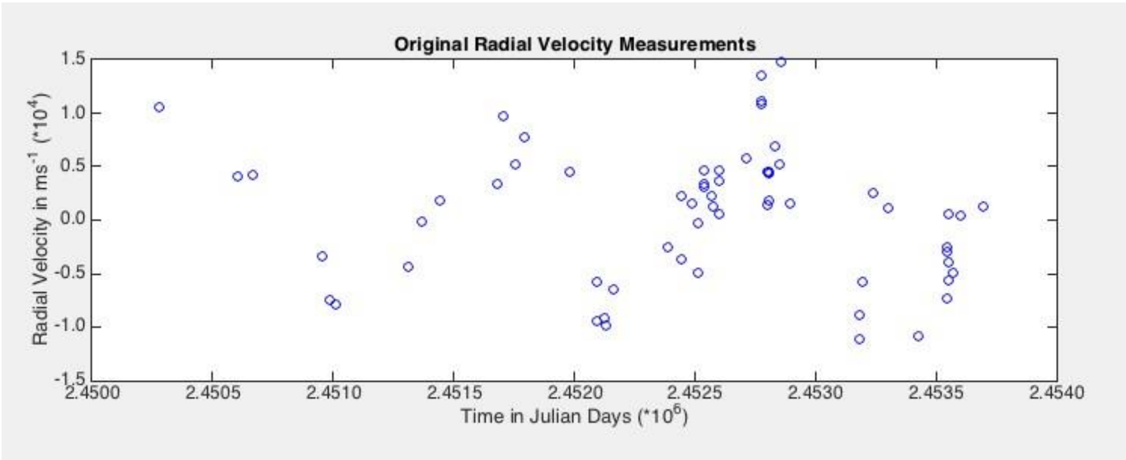

Fig. 1 Observed radial velocity curve of the star HD 164922.

and the orbital shape parameters (eccentricity, time of the periastron, true anomaly, etc.), we employed the Systemic 2 software [6]. Systemic 2 works by fitting a computer model of planetary orbits to radial velocity data. The best-fit parameters determined with this software were then used as input for a computer model that was coded in MATLAB [7] to produce Fig. 2. This figure shows different possible frequencies of the Radial Velocity data with the higher peaks having greater probability of being real rather than just due to random data fluctuations. The two peaks that have been circled were significantly larger than the average and show great potential for planets matching these frequencies.

2.2. Transit Method.

To identify extrasolar planets with the Transit Method, we obtained archival data from NASA's Kepler Mission archives [8]. The data available in this archive was in Flexible Image Transport System (FITS) format [9], with up to six years of data per star contained in multiple files of around twenty per star. These files were read with the MATLAB fitsread command. MATLAB was then used to write programs to manipulate the data so it could be analyzed correctly. In order to adjust the fluxes of each star to the same average value, simple linear shifts were applied to the archival files. Because detection of transits only relies on relative flux variations, absolute calibration of the flux levels in each data file was not a concern in this analysis. Observing times and adjusted light fluxes from every file were then concatenated in order to be able to show orbits with periods that are longer than those contained in an individual files. The data was then smoothed using a 15-point moving average in order to reduce the effect of noise. A typical light curve of a star with a transiting planet is shown in Fig. 3 and a potential one in Fig. 4. Fig. 3 is data from a star that was confirmed to have a planet orbiting it, and was used as a reference to see if these methods could reproduce accepted results. It also serves visually to show how much the light has decreased from the average value between the two types. Fig. 4 is data from a star that has no confirmed planets orbiting it, and is one of the 10 candidate data sets analyzed in this research. It shows similar trends as the confirmed data set, but with dips that are closer to the mean data. Both figures display only a part of the entire data set for easier viewing, as data was collected for four years. These graphs were then visually analyzed to see if a potential orbital period could be determined.

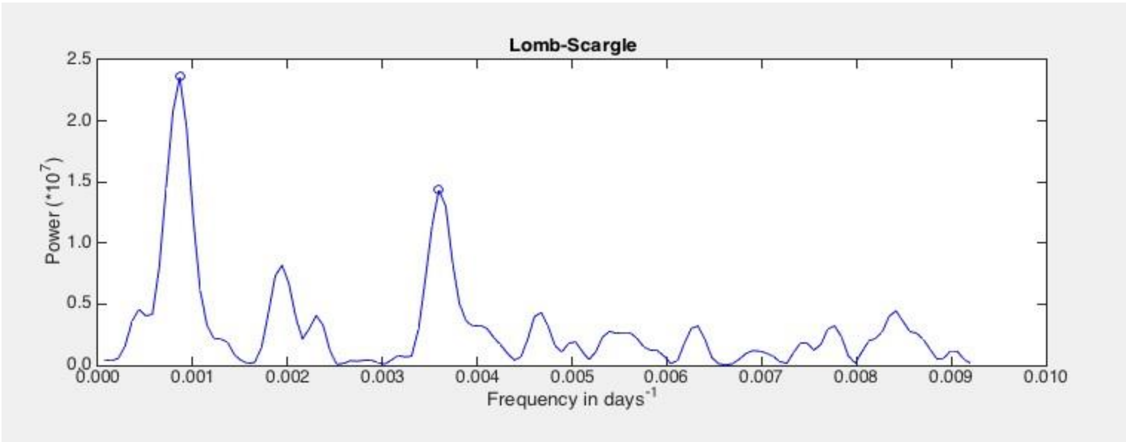

Fig. 2 Radial Velocity scatter plot and Lomb-Scargle Periodogram for Star HD 164922.

3. RESULTS and DISCUSSION

3.1. Radial Velocity Method.

Fig. 2 shows the frequency spectrum of HD 164922, which we derived from its radial velocity data using the Lomb-Scargle method. The power shown on the vertical axis is a measure of the prevalence of certain frequencies in the radial velocity data. The greater the power, the more likely that a peak appears due to an orbiting planet rather than random fluctuations in the data. The most prominent peak in Fig. 2 at a frequency of 0.0009 days^{-1} corresponds to the orbital period of the known planet HD 164922b [10], thus demonstrating the viability of our radial velocity analysis method. We note that there is a second strong peak with frequency 0.0037 days^{-1}, corresponding to a period of approximately 270 days. This may suggest the presence of a second planet that has not yet been reported in the literature.

Table 1 lists the best-fit orbital parameters of HD 164922 derived with Systemic 2. Fig. 5 shows the theoretical radial velocity curve we computed from these parameters. For comparison, we show the published radial velocity curve for the same star in Fig. 6. The consistency of the physical parameters and theoretical radial velocity curves derived in this study confirm that our method is capable of detecting extrasolar planets and deriving their physical parameters from archival radial velocity data.

RV Curve Estimated Parameters	
Period (*P*)	3.1489 years
Time of Periastron (*Tp*)	1995.525 years
Eccentricity (*e*)	0.09589
Barycenter Velocity (*Vo*)	0
Semi-Amplitude (*K*)	3.441273
Longitude (*ω*)	7.653 m/s

Table 1. Estimated parameters for Radial Velocity (RV) using Systemic Console 2 Software. P is time of orbit, Tp is time when the planet is nearest to the star, e is the deviation of the circular or- bit, V0 is center of mass of the system velocity, K is half of height of wave peak to peak, and ω is the east-west coordinate.

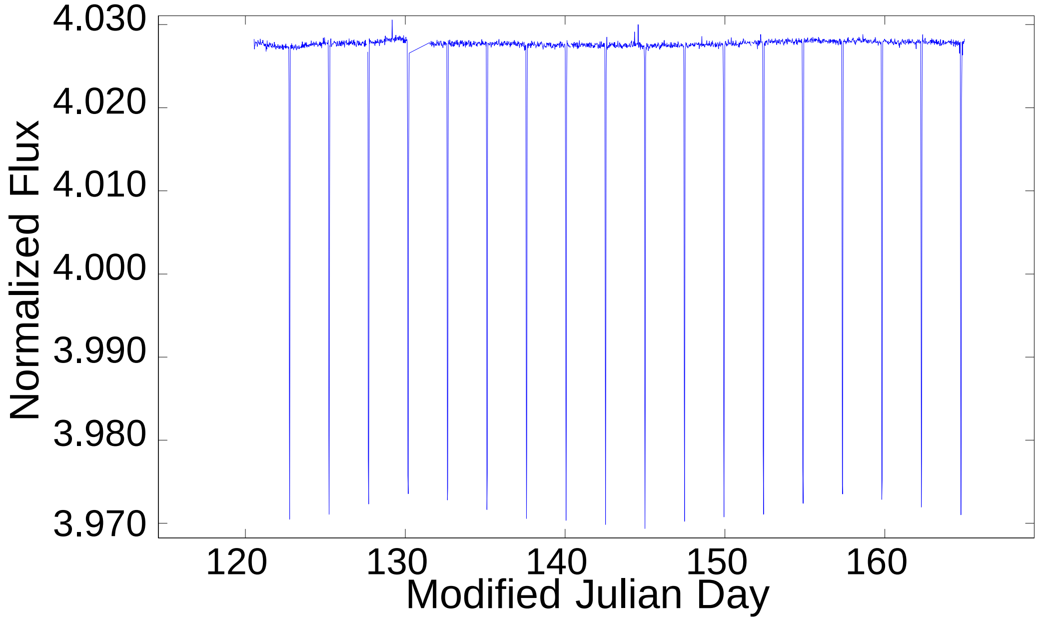

Fig. 3 This graph shows a confirmed planet in our study (Kepler ID 11446443). The dimming of the flux (arbitrary units) by 1.5% due to planetary transits occurs at regular 2.5-day intervals. The period determined in this study matches the value published in the Kepler data archive.

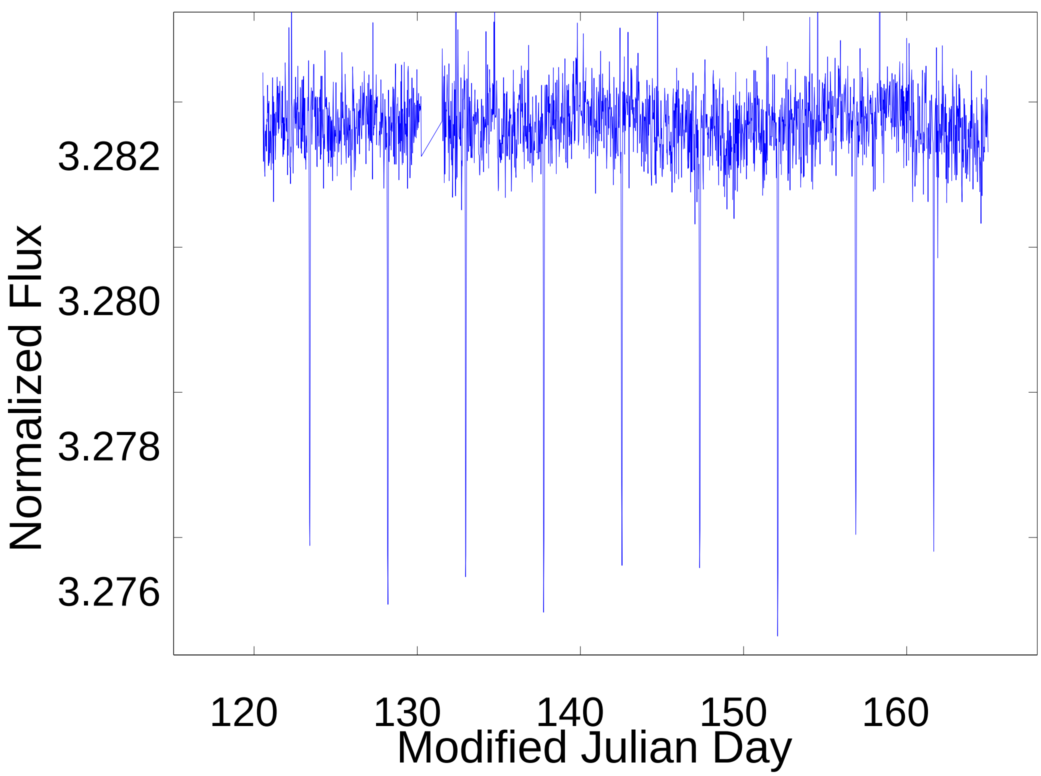

Fig. 4 A candidate planet in our study with a period of 5 days (Kepler ID 8554498). Note that dimming during planetary transits is much smaller (approx. 0.1% of the stellar flux, which has arbitrary units) but still significantly greater than three times the standard deviation, which is the limit we adopted in this study.

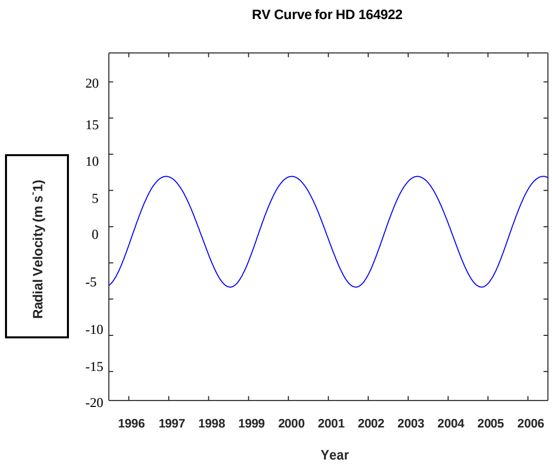

Fig. 5 Radial Velocity curve of HD 164922 generated using MATLAB software.

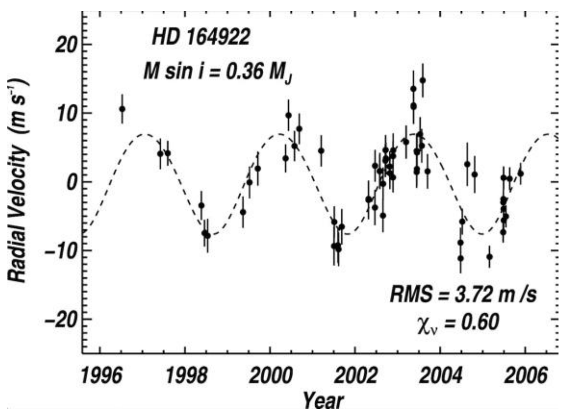

Fig. 6 Published radial velocity curve for the star HD 164922 [10].

3.2. Transit Method.

Fig. 3 and Fig. 4 show the light curves of two planetary systems with period of 2.5 and 5 days with Kepler ID's of 11446443 and 8554498. During each transit, the observed fluxes of the stars dip by 1.5% and 0.1%, respectively. Note that the ratio of the magnitude of the dimming to the standard deviation of the flux is much smaller in Fig. 4 than Fig. 3, which is approximately ten. We only considered planetary candidates for further study if this ratio was at least 3 and if the dimming occurred at regular intervals. Dips that are under three times the standard deviation may be too close to the average data to guarantee they are not simply random fluctuations in data.

They needed to also have regular intervals between the dips as planets would have a specific period for their orbit around a star while irregular dips could be caused by other things such as comets passing by. The majority of candidates were eliminated as false positives because they did not meet both of these criteria (e.g., random dimming due to background noise or transient phenomena that are unrelated to planetary transits). The candidates analyzed are: Kepler ID 8554498, 9527334, 6056992, 7199397, 8056665, 8505215, 4055765, 8456679, and 2444412. All derived periods were consistent with published values in the Kepler data archive, confirming that our method for analyzing transit data is vi- able and can be used in the search for new planetary systems.

4. CONCLUSION and FUTURE WORK

The main purpose of this research was to build computer code to analyze data on extrasolar planets using the Radial Velocity and Transit techniques, and to compare them to published results of confirmed planetary systems. We have successfully developed tools for determining physical parameters of such systems using our own computer code and the Systemic 2 software.

Using the Radial Velocity method, three orbital periods were found for potential planets and five were found using the Transit Method for different planets. As next steps, we plan to (1) employ these tools to archival data sets that have not previously been analyzed, in order to discover new extrasolar planets, (2) conduct searches for additional planets in systems that already have one or more confirmed planets, (3) evaluate more reliable methods for discriminating between genuine planetary systems and other contaminants masquerading as planetary systems, such as binary stars, and (4) develop our own computer model similar to that used in the Systemic 2 software that allows us to simulate planetary systems with different masses and orbital shapes.

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AUTHOR CONTRIBUTIONS

J.P. and K.L. worked on developing the code and researching information for the Transit Method while K.S. and S.M. did the same for the Ra- dial Velocity method. All faculty members created the idea of the project and provided guidance to understand new information and trouble shooting code.

References

[1] Mayor, M. and Queloz, D., Nature, 378 (1995), 355–359.

[2] Koch, D., Borucki, W., Lissauer, J. J., Dunham, E. W., and Jenkins, J., BAAS, 30 (1998), 1535.

[3] Holman, M. J. and Fabrycky, D. C., Science, 330 (2010), 51–54.

[4] Wright. J., exoplanets.org, (2016).

[5] Scargle, J. D., ApJ, 23 (1982), 835–853.

[6] Meschiari, S., PASP, 121 (2009), 1016–1027.

[7] MATLAB, MathWorks, (1994-2016).

[8] Swam, M. S., Swade, D., Sontag, C., Heller-Boyer, C., Gaffney, N., and Kidwell, R., ASP, 376 (2007), 209–212.

[9] Verner D. A. and Yakovlev D. G., Astronomy and Astrophysics Suppl., 109 (1995), 125-133.

[10] Butler, R. P., UCP, 646 (2006), 505-522.