Distribution of Planets in Multi-Planetary Exo-Solar Systems. S. T. Port[1,2], J. A. Heydenreich[1,3], and Z. M. McMahon[1,4], [1]Arkansas Center for Space and Planetary Science, University of Arkansas, [2]saraport@uark.edu, [3]jaheyden@uark.edu, [4]zmmcmaho@uark.edu.

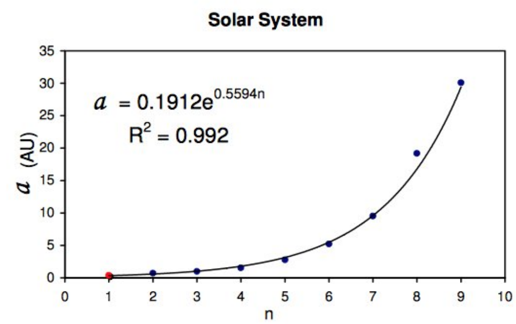
Introduction: Through the use of modern technology, such as the Kepler Space Observatory, hundreds of exoplanets have already been discovered and confirmed, while thousands more are expected to exist. Some of these planets are now known to be one of many planets orbiting a host star. These multiplantary systems are actually a common occurrence, thus with a large sample size it is possible to study correlations between these planetary systems [4].

Our goal is to determine if there exists some factor, or factors, that determines the arrangement of exoplanets within exo-solar systems. The determination of a relation to the arrangement of the exoplanets can aid in the understanding of how solar systems form. This can give us an approximation of where in the orbital plane a planet will form. With this knowledge it may be possible to estimate how many planets are in a given system and determine the location of planets not yet discovered. If a planet is not where it is expected to be, then that may be indicative of characteristics or processes particular to that individual system. In order to find a relation we evaluated systems that contained multiple planets. This was accomplished using a database of multi-planetary systems that we built from existing databases, namely the NASA Exoplanet Archive as well as [2], and [3]. Using this data we were able to construct graphs and formulate equations that relate to each individual system.

To focus our efforts, we began by studying and applying the Titius-Bode relation for each system. Since the Titius-Bode assumes several factors based on our own solar system minor modification were needed in order to apply it to other multi-planetary exo-solar systems. Using this equation we attempted to observe a relation, or the lack thereof, in regards to the arrangement of the planetary system. The data attained from this study can be used to compare other systems to each other and to our own solar system [1], [5].

Methods: The basis of our research was to examine if the Titius-Bode Law could be applied to exoplanets. The Titius-Bode relation is a geometric progression, n, of a planet's distance from its star. A simple exponential relation for the Titius-Bode law was necessary to allow for a larger range of a values [1]. The relation used was $y = a * e^{bn}$, and so ln(y) = ln(a) + b·n where b is the slope, n is the planet rank, and *ln(a)* is the y-intercept. By plotting the rank of the planet by the natural log of the semi-major axis of each planet we determined the slope and y-intercept. We solved for a by taking the exponent of the y-intercept then plotted the slope by the calculated a value. Each system can be individually plotted in an exponential trend as seen in Fig. 1. This verified that the simpler equation works by applying it to our solar system.

a)



b)

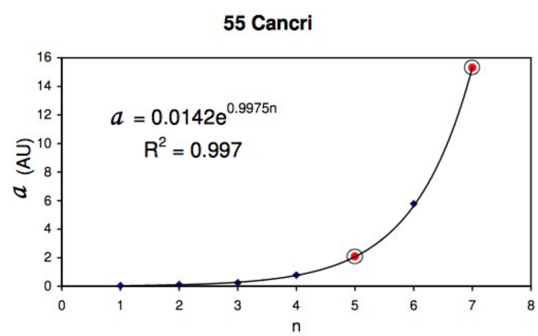


Figure 1: Figure 1a demonstrates the correlation of the distance between each planet and the host star versus the planet rank for our solar system. Figure 1b demonstrates the same correlation, but around the binary star system known as 55 Cancri.

First, we separated out all the systems with four and/or more planets within the system. Then we used the semi-major axis and rank to calculate the slope and intercept for each system to create a simpler equation and plotted the results. Fig. 2a shows the planets with their natural rank plotted. In Fig. 2b we altered the rankings of all the systems to begin at n=0. This change was made because systems could have planets such as Mercury, were the first planet is not exactly at n=1 [1].

Using data attained from various sites ([2], [3], and [4],) we also plotted the slopes of each planetary system against the stellar characteristics of their host star. These characteristics included the stellar radius, stellar mass, metallicity, stellar age and the effective temperature of the host star.

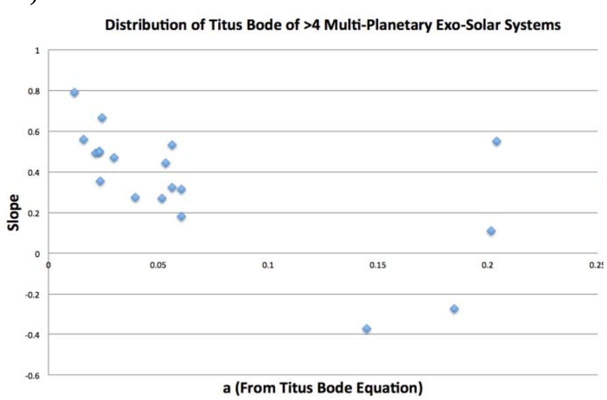
Results: At the start of the experiment it was found that when the rank number started at n=1, the intercept values of each of the systems showed a better correlation than the slope. However, when the rank was first set to zero the slopes of each data displayed a better relationship. Therefore it was decided after early analysis to start the starting n value to zero.

As can been seen in Figure 2, the majority of the data points are closely clustered therefore indicating some relationship. All of the data points are near a Titius-Bode *a* of 0.04.

One interesting result observed was there was no correlation between the slopes and the number of planets per system. As can be seen in the Figure 2, all data points, no matter the number of planets per system, are all centered on the same region on the graph.

In regards to the slope versus the stellar characteristics no direct correlation was revealed.

a)



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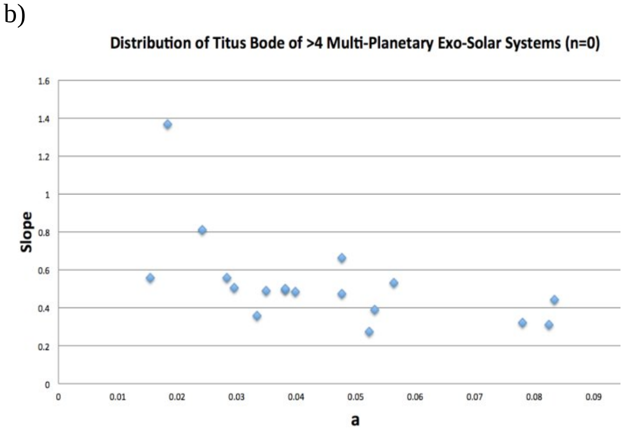

c)

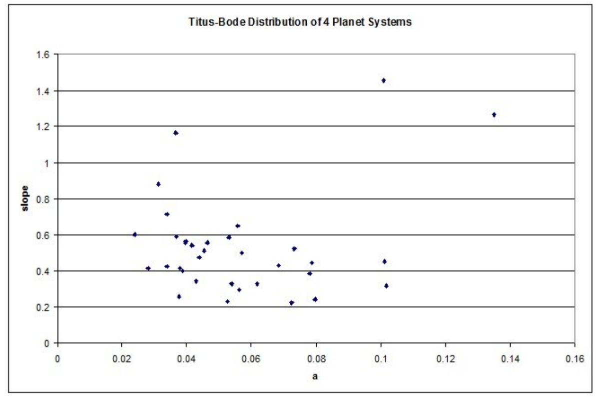

Figure 2: Figure 2a displays the distribution of planetary systems with more than four planets and the first n set to one. Figure 2b is the same as Figure 2a except that the first n is set to zero. Figure 2c graphs systems with four planets with a starting n of zero.

Conclusion: Overall, the Titius-Bode Relation was found to be flexible and applicable to many other solar systems other than our own. It also exhibits a good correlation between the various planetary systems. The one planetary system that did not show a stronger relation was our own solar system. It is believed that this is due to the close proximity of Mercury to the Sun.

Future: At this moment only planetary systems with 4 or more orbiting planets were used. In the future we aim to incorporate planetary system with 3 planets. The database we used to attain our values also only gave the planets that have been confirmed. We hope to integrate unconfirmed planets into our data in the future. We also plan to learn more about the stars that each system revolves around to observe a correlation between binary or trinary star systems.

With the increase in modern technology scientists are now able to identify young protoplanetary systems as well as dust belts and rings around host stars. We expect to insert these into our models to observe if we can detect if these bands are or will form into planets in the future.

References: [1] Poveda A. and Lara P. (2008) Revista Mexicana de Astronomia y Astrofisica, 44, 243-246 [2] openexoplanetcatalogue.com [3] exoplanet.eu [4] http://exoplanetarchive.ipac.caltech.edu/ [5] Hayes W. and Tremaine S. (1998) Icarus, 135, 549-557