Searching for Transients in the Kepler Mission Data

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Abstract: *Since early 2009, the Kepler spacecraft has continuously monitored over 150,000 stars in a 115-square degree field of view located in the constellations Cygnus and Lyra. Though the goal of the Kepler mission is to find extra-solar planets, another use of the Kepler data includes studying the behavior of normal and variable stars in the field. Every month Kepler downloads a full-field image consisting of 84 charge-coupled device channels. In this research, images acquired at the beginning of the mission have been subtracted with later images to search for transient astronomical events, such as novae and supernovae, and variable stars not yet identified from this field. Approximately 1000 variables have been found, with a number of these being possible transients. These candidate variables and transients are compared with known variable star catalogs to determine which are newly discovered objects. A fraction of these new objects will be selected by Kepler for continuous study in Cycle 3.*

Keywords: *Kepler, transient, variable, supernova,*

Introduction

Launched in March 2009 to estimate the number of Earth-sized planets within and near the habitable zone of solar-type stars, National Aeronautics and Space Administration's (NASA's) Kepler Mission tracks over 150,000 stellar objects continuously in a field of view within the constellations Cygnus and Lyra. NASA finds these planets by searching for transits, astronomical events that take place when one celestial body, such as an Earth-sized planet, crosses in front of - or what appears to be in front of - another celestial body, or in this case, a star. Currently, those working on the Kepler Mission have identified 997 stars containing a sum of 1235 planetary candidates (Borucki, W. J., et al. 2011).

The array of CCD imagers has a wide field of view - 115 square degrees - specifically so that Kepler keeps a constant eye on an area with a high stellar density of dwarf stars. The photometer was designed based on a modified Schmidt telescope; more information about this can be found in Borucki, W. J., et al. (2010) and Borucki, W. J., for the Kepler Mission (2010). There are 42 charge-coupled devices (CCDs) that are 1024 rows by 2200 columns. With two amplifiers per CCD, Kepler runs 84 channels; furthermore, the CCDs are mounted as pairs, meaning there are 21 modules. This can be seen in Fig. 1.

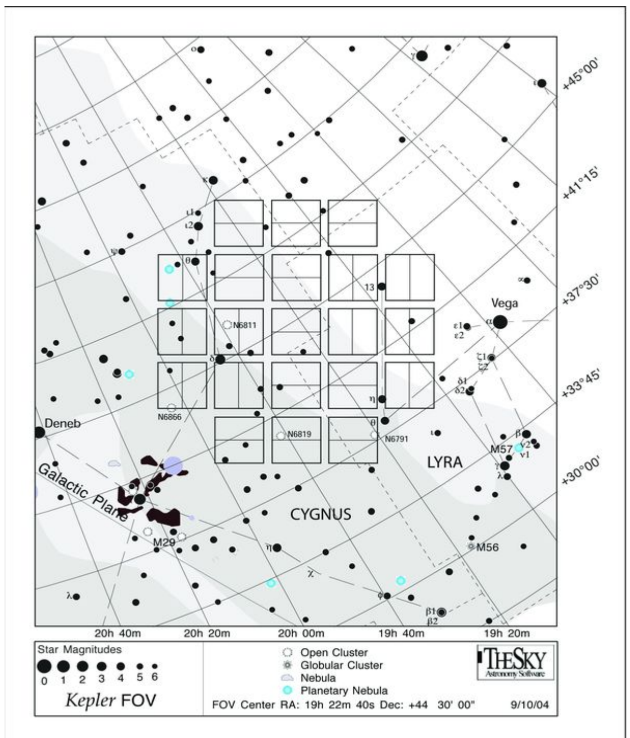

Figure 1: This image[1] displays the 42 CCDs paired into 21 modules in an image of the sky.

The data collected by Kepler is recorded in segments of quarter-years, as it is necessary for the spacecraft to rotate consistently and sequentially 90 degrees in order to illuminate the solar arrays and keep power running on the spacecraft. Due to the quarterly rotation of the spacecraft, the images of the stars are recorded on a different set of detectors (Borucki, W. J., et al.

[1] The original image can be seen at <http://kepler.nasa.gov/multimedia/Images/photogallery/?ImageID=12 >. Software Bisque is credited with the information given on the webpage.

2011). As is noted in Gilliland, R. L., et al. (2011), if an object begins at Quarter 2 in channel 1, it will move to channel 53, 81, 29, and then back to channel 1 for Quarters 3, 4, 5, and 6, respectively. Also note that during Quarter 4, two CCDs - or four channels - were damaged in module 3: channels 5-8. These channels were not used in our data.

A second application of the Kepler Mission data is to detect and observe variable stars and transient astronomical events, or transients. Common transients include novae and supernovae, the latter being an important and desired find. We have an active program with Kepler to look at ~100 galaxies in the Kepler field of view in order to search for supernovae.

The purpose of this paper is to describe the process and results of searching through the Kepler Mission data to find possible variable stars, transients, and ultimately, supernovae. If a supernova is discovered in the data, we can access the images that recorded the beginning of the explosion. In certain kinds of type Ia supernovae, it is expected that a shock emission can occur less than a day after the explosion (Hayden, B. T., et al. 2010). This shock emission is due to some of the ejecta of the supernova smashing into the companion star. Simulations of this shock have been made and analyzed, though very few actual shocks have been observed. By looking through the Kepler data, we have the possibility of discovering a supernova with this characteristic in order to better study and understand the event.

Experiment

Utilizing the link to .fits full frame images (FFIs) provided by NASA's Kepler Data Analysis webpage, we accessed the monthly image downloads from Quarters 1 through 9. Due to the orientation changing each quarter by 90 degrees, we determined it best to choose similarly-oriented quarters; in this manner, we ensure that as few stars as possible leave the frame or change CCDs. This process makes it manageable to align and combine or subtract images for comparison. We selected the orientation that Quarters 1, 5, and 9 share, as it had the most available combined data.

Eight images for the Kepler Quarter 1 observation were recorded during the late part of April 2009. Though the rest of the images we will discuss are monthly images, it appears these were taken in three successive days. The Kepler Quarters 5 and 9 observations occurred from April to June 2010 and 2011, respectively. Quarter 5 included three images, one from the latter part of each month, while Quarter 9 contained only two images, as the one from June is not yet released.

Image Reduction and Analysis Facility (IRAF), a software system with the purpose of processing astronomical data, was used to prepare the images. After all thirteen images were downloaded from Kepler, we utilized IRAF to separate each of the images into their respective 84 channels, funneling them into 84 subdirectories. We applied a script to each of the subdirectories that combined all of the Quarter 1 images into a template image. The brightness values of the template and Quarters 5 and 9 images were then divided by 100,000 in order for the next few steps to run more smoothly.

To prepare for the alignment and subtraction of the images, pixel coordinates of at least three non-saturated, well-focused stars were written into a .stamps file. This provides markers for the program, so it can recognize what to use for matching the point-spread function of the images. After completing the above steps, we were able to run *snphot_new*, a program designed by Brian Schmidt, a researcher at Australian National University, in order to align each channel's Quarters 5 and 9 images to the respective template; the template was then subtracted from each of the respectively aligned images.

I visually searched for events and stellar objects that were incommensurable in the subtractions with "ds9", an imaging and data visualization application that displays .fits images. For every variant, I noted the celestial coordinates and a comment about the characteristic of the variant recognized. This was done to compare the results with current catalogs of extra-solar bodies, such as the Set of Identifications, Measurements, and Bibliography for Astronomical Data (SIMBAD) and the General Catalog of Variable Stars (GCVS). SIMBAD includes a catalog of known variables in the Kepler field.

Data

Shown in Fig. 2 is a 1024x1100-pixel template image from channel 50. Noticeable traits are the star cluster NGC 6819[2] and scattered bright stars, separated by dimmer stars as a light background.

[2] Information about this star cluster can be seen at <http://helas.astro.uni.wroc.pl/data/kepler/pulsating_stars_-_Kepler_FOV/OC_Kepler.html>.

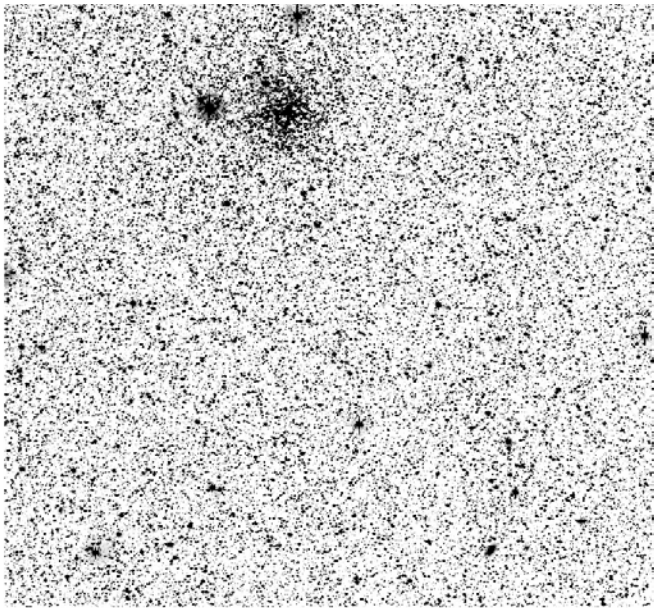

Figure 2: The template image (opposite contrast) taken from channel 50. Note that it has 1024x1100 pixels.

Figure 3 is a display of a candidate transient found in channel 58 at right ascension 19:28:36.52 and declination +47:51:22.70. The transient is the faint object that lies directly above and to the right of the crosshairs.

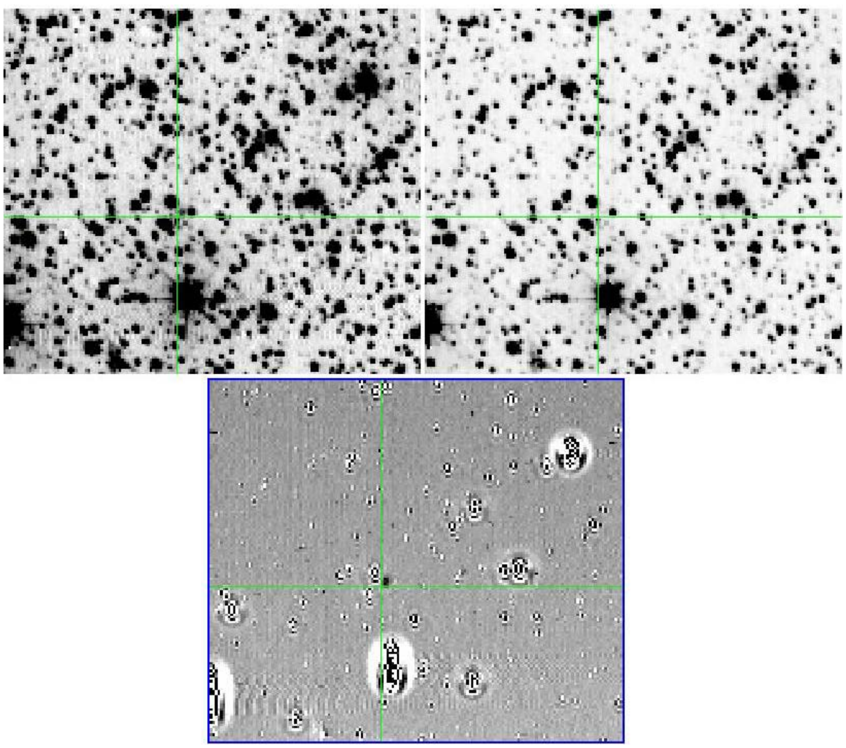

Figure 3: A Quarter 9 image of channel 58 (top-left), the template image of channel 58 (top-right), and the Quarter 9 subtracted image (bottom) are shown in opposite contrast. The candidate transient is located to the upper right of the each crosshair.

Table 1 displays 14 significant variables/transients. One is noted as being recognized by SIMBAD.

Channel	RA	Dec	SIMBAD
02	18:49:25.42	+43:39:52.61	-
09	19:05:52.79	+39:55:21.66	-
09	19:04:28.43	+40:05:06.15	-
12	19:02:30.29	+39:44:19.42	-
14	18:48:18.55	+47:07:45.15	-
17	18:58:16.14	+46:13:35.14	-
17	19:03:37.39	+45:48:17.27	-
28	19:16:16.66	+38:58:11.05	-
40	19:12:35.19	+48:07:08.55	-
42	19:21:54.71	+44:08:59.75	-
53	19:25:44.54	+51:09:31.20	V* V1119 Cyg
58	19:28:36.54	+47:51:22.70	-
73	19:45:18.02	+48:59:42.16	-
75	19:40:09.08	+50:48:17.47	-

Table 1: “Channel” refers to one of the 84 channels from which the significant variable/transient came. “RA” is right ascension while “Dec” is declination. “SIMBAD” refers to the name SIMBAD recognized if the object existed in the catalog.

Results and Analysis

A meticulous search for variables and transients in all 84 channels of the Kepler Quarters 5 and 9 monthly images resulted in 1042 candidates being found. Of these 1042, 14 candidate variables/transients have been marked as unique or significant. This marking signifies that the candidate was peculiar or dissimilar to the others in a noticeable manner. These can be seen in Table 1. For example, in Figure 3, the object identified as the possible transient is not noticeable in the template image, a compilation of images from April 2009. However, nearly two years later, it is recorded as existing in the two Quarter 9 images and subtractions.

Though many of the 1042 candidates may be known stellar objects and variables/transients, we suppose that a number of these are objects yet to be identified from the Kepler Mission data. Providing 1042 candidates for the catalog, SIMBAD recognized 240 as having celestial coordinates within 20 arc seconds of their identified stars, while only one of the 14 significant variables/transients was recognized by congruent standards. Further analysis will be done in the future to determine the significance of these findings, and some will be selected for further study by Kepler in Cycle 3.

Conclusion

The Kepler Mission, starting in the spring of 2009, monitors ~156,000 stars in a field of view within the constellations Cygnus and Lyra. Utilizing the data collected since the beginning of the mission, we have processed images from Quarters 1, 5 and 9 to search for variable stars and transients. After visually surveying each of the 84 channels individually, we have identified 1042 candidates. In this paper we display a table of 14 significant, or unique, candidates. These candidates are compared with known variable star catalogs, i.e. SIMBAD and GCVS, to determine which are newly identified variables/transients; furthermore, a portion of the 1042 candidates will be chosen for study by Kepler in Cycle 3.

References

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