False Positives in Photometric Planet Detection with Vulcan

Peng Yav, San Jose State University
Advisor: Dr. Natalie Batalha, San Jose State University

Background eclipsing binaries have presented themselves as false positives in photometric planet detection. Finding the optimal aperture size as a magnitude of stellar flux can help in reducing the occurrences of false positives in the Vulcan project pipeline. The false positive rate can be reduced when using an optimal fitting radius. The information gathered will be used to help modify the Vulcan pipeline algorithm.

Introduction

The objective of my research this summer was to find the optimal photometric fitting radius as a function of star flux (ADU) based upon the observation of a standard growth curve analysis. One of the things we wanted to do was remove the occurrence of false positives in the Vulcan pipeline algorithm. By determining an optimal fitting radius, we can reduce these occurrences, which are primarily due to background eclipsing binaries. The reduction of false positives can help to improve the efficiency of the Vulcan data reduction pipeline. The information from the optimal fitting radius can be derived from the growth curve analysis and can then be used to help modify the Vulcan pipeline algorithm, which uses empirical point spread function fitting with millimagnitude precision.

Background on Photometric Planet Detection

The science behind transit detection involves an object (planet) and a star that it revolves around. As the planet orbits the star and when it is within the line of sight, the eclipsing of the star by the planet can be observed through the measurement of a light curve. The result is a very slight decrease in the magnitude of the star over a period of time (see Figure 1). To detect planet transits, we can look for them from two locations, on Earth and in space. On Earth, we use ground based telescopes to detect planets that are about the size of Jupiter (Jovian-sized). Planets of this size typically deplete about 1% of the star's total brightness (Batalha et al. 2001). Detecting planets the size of earth with ground based telescopes would be unlikely due to noise sources introduced by Earth's atmosphere, which causes scintillation, turbulence, and the index of refraction to change. With spaced based telescopes, they are located outside the Earth's atmosphere and thus are unaffected by the noise source. In addition, they are not disturbed by rotational movement of the Earth and therefore can stare at the same field of stars for a very long period of time (4 years for the Kepler project). Detecting a planet the size of earth (terrestrial sized) would show a depletion of 0.0008% of stellar brightness. The NASA Vulcan Camera Project was designed to detect Jovian sized extra solar planets. At the same time it is also a test bed for the future NASA Kepler Project, which is located in space and is designed to detect earth sized extra solar planets.

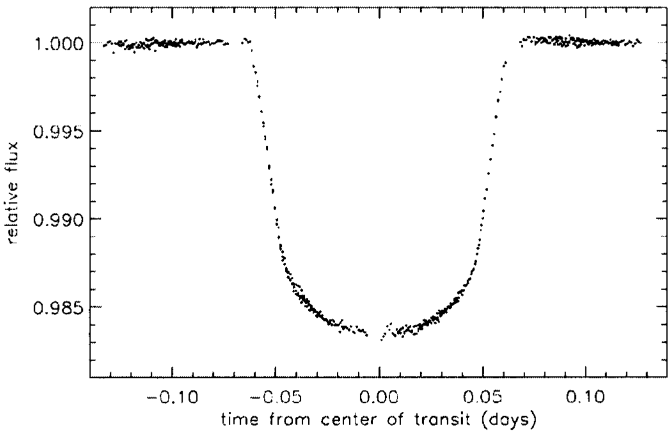

Figure 5. HD 209458: A light curve showing a reduction in flux caused by a transiting planet. Data from the Hubble Space Telescope (Brown et al. 2001)

3. OBSERVATIONS AND REDUCTION

The images provided are from the NASA Vulcan project, which examined a field of stars in the constellation of Cygnus. This is the same field of view as the NASA Kepler project. The images were taken on October 20-23 of 2005. The camera field of view is 7×7 degrees with a focal length of 28 cm and an f stop of 2.8. This reveals a star field consisting of ~100,000 stars with a resolution of 4096×4096 pixels with each pixel measuring ~6″.

The reduction and preliminary analysis of the existing data has been the primary aspect of work done this summer. Using standard CCD image calibration procedures, I reduced the image for the aperture fitting process. This involved reduction procedures including bias subtraction and flat field normalization. Additional measurements were taken from the image itself, which included the full width half maximum (FWHM), sky value, sigma, read noise, gain, and background sky values.

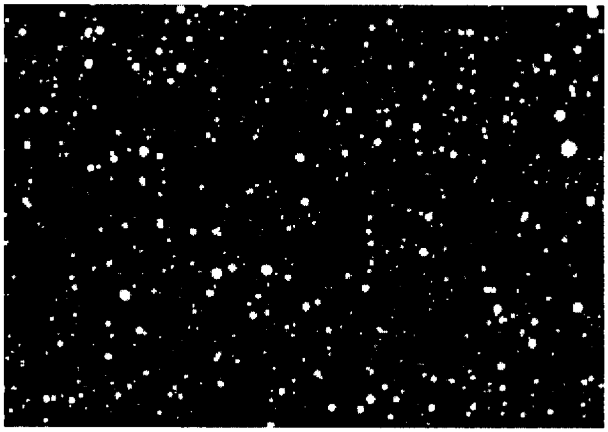

Figure 2. A section of the central area of the star field image displaying relatively round stars.

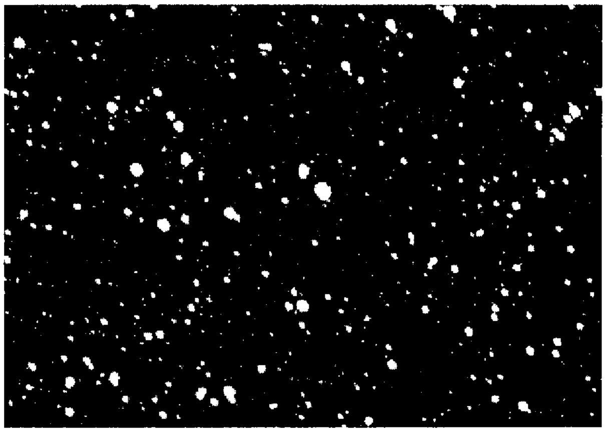

Figure 3. A section of the top left corner of the star field image displaying contorted and slightly elliptical stars due to the lens' focal plane and large field of view.

Detecting planets in a large field of view requires high precision photometry to detect the miniscule changes in brightness. However, the large field of view and the lens' focal plane causes stars in the four corners to be elongated. Fine tuning of the of the *'roundness'* and *'sharpness'* parameters in the IRAF *'daofind'* task allowed the inclusion of contorted stars and exclusion of spurious stars. Although the task did include some spurious stars, the number was negligible.

Upon receiving the data, a small but very important parameter had to be taken into account prior to performing the image reduction tasks. The fits file format consisted of a header flag by the name of SIMPLE, which was currently set to F (false). Further access or manipulation of the file by IRAF could not be achieved unless this value was changed to TRUE. A relatively simple Perl script was written by me to modify this part of the header. The script was set to perform a batch process of any files in the directory having a .fits extension. The script would read in the file as binary and perform a search and replace on the "SIMPLE = F" ascii text and change it to "SIMPLE = T" and then output it along with the header text and binary portion of the file to a new file and save it under the original name.

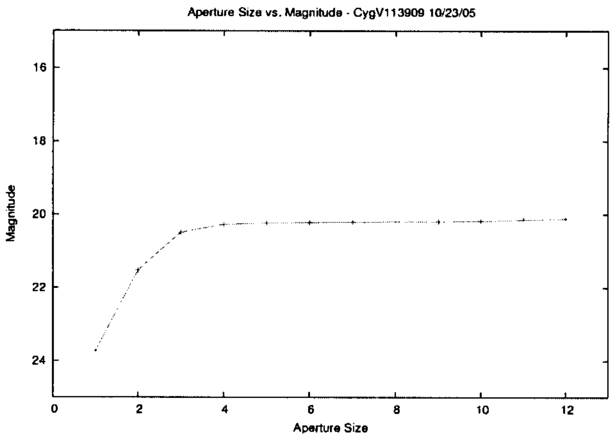

Figure 4. A plot of aperture size vs. magnitude. As the aperture radius increases, the magnitude decreases (gets brighter) up until the point spread function (PSF) goes to zero. This is the point where the slope levels off.

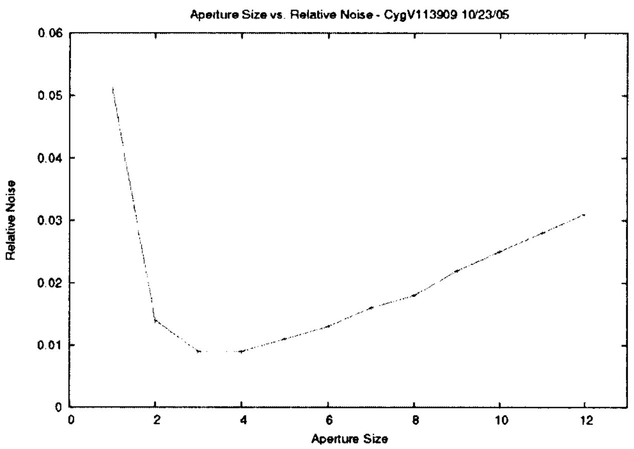

Figure 5. A plot of aperture size vs. relative noise. As the aperture radius increases, the level of relative noise increases and continues to do so with the increasing radius.

Analysis

Aperture photometry involves the task of finding a star, picking an aperture size, summing up the detected light and then estimating and subtracting the background noise. However, when performing this task on thousands of stars require that we find an optimal aperture size. Generally, a large aperture will provide more flux from the star within the aperture, but drawbacks include a larger error from the sky subtraction as well as increased cosmic ray events from within the aperture. Choosing a small aperture allows less error from sky subtraction and less cosmic ray events, but may prohibit all the flux from the star to be accounted for. Deciding on an optimal aperture size requires that we perform a growth curve analysis. We do so by measuring the magnitudes of stars with successive large apertures. The magnitude increases as we increase the aperture size to a certain point and then it levels off as the point spread function (PSF) goes to zero. The point before the PSF goes to zero is our optimal radius because we have maximized our flux (ADU) counts as well as reduced the relative amount of noise (see Fig. 3.). Relative noise is taken into consideration because as the aperture size is increased, so does the level of noise included within that aperture radius. Finding the optimal aperture size will also yield the lowest amount of relative noise (see Fig. 4). The stars with the larger magnitudes (brighter) will require a larger optimal aperture size. Figure 6 shows the optimal aperture size as a function of stellar magnitude.

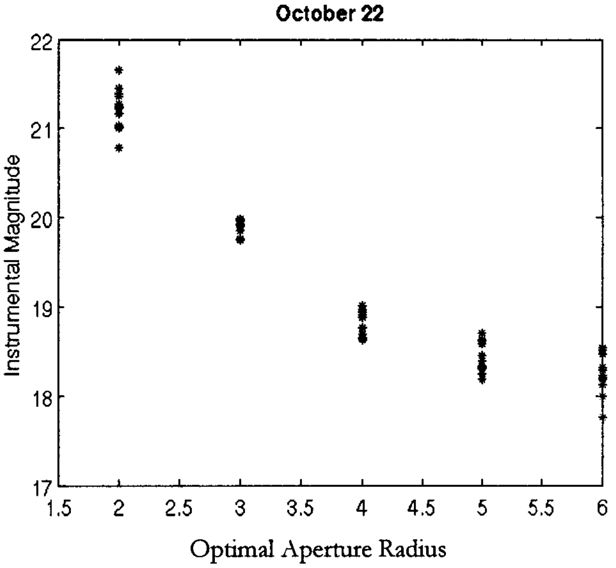

Figure 6. Histogram of different magnitudes based off of 16 quadrants of the image where each asterisk represents an average magnitude in a quadrant measured by the corresponding optimal aperture radius size.

Conclusions

The fitting radius of the Vulcan pipeline is 5 pixels, so occasionally, background stars fall into this fitting radius leading to contamination and false positives. The false positive rates can be reduced when an optimal fitting radius is applied because contamination from nearby background stars is minimized. However, careful consideration must be taken into account in regards to the fitting radius because the relative precision will decrease if the chosen fitting radius is made too small.

Acknowledgements

The author would like to thank the director of the SDSU REU program, Dr. Eric Sandquist, for organizing this summer's event; my advisor, Dr. Natalie Batalha, for all her help and advice and in helping to keep my sanity; Dr. Maura Rabette, for providing additional assistance when Dr. Batalha was not around; the SDSU Astronomy faculty, staff and students for hosting the event; and the National Science Foundation for making all this possible with their generous funding.

References:

Batalha, N.M., Jenkins, J., Basri, G. S., Borucki, W. J., Koch, D.G. 2001, ESA, 485, 1

Borucki, W. J., Caldwell, D., Koch, D. G., Webster, L. D., Jenkins, J. M., Ninkov, Z., Showen, R. 2001, AAS, 24.01, 1

Brown, T. M., Charbonneau, D., Gilliland, R. L., Noyes, R. W., & Burrows, A. 2001, ApJ, 552, 699

Charbonneau, D, Brown, T. M., Dunham, E. W.; Latham, D. W.; Looper, D. L.; Mandushev, G. 2004, AIP, 713, 151-160.