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PHYS 3070 Exoplanetary Project

Transmit method

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WASP-2b & WASP-2

***Introduction and Background Data*:**

Known as, GSC 00522-01199, Considering as an extrasolar planet and is orbiting around WASP-2 “star”. It appears like an orange dwarf star (it has a spectral type of K1V), this start is in the northern constellation of Delphinus. Has an orbital period of 2.152 days. In the beginning of 2004, the physicists suggested that this is consider as a planetary system since it follows all the requirements to be a planet and a star, transit of the planet crosses in front of its star. As we know, the transit method looks for the dimming of the light from a star caused by planets passing in front of them in eclipse (biased towards large, close-in planets with short periods). Recently, any random project related to an extrasolar planet has been a major topic of discussion across most astronomers and physicists. Over the last decades, especially after a massive development of space-based telescopes, NASA exoplanetary science department has enhanced forward at an extraordinary rate. Thousands of these celestials have been discovered, and the list grows day-to-day. There are a variety of approaches used to spot an exoplanet, such as the radial velocity method, *“the transit method”*, direct imaging and gravitational lensing. In the transit method (as we mentioned above), the planet cross by a host star, hiding some of its light. The plane of this orbit happens to line up with the host at which we can observe this system, henceforward we will be able to detect the drop-in light. WASP-2, considered as the first target which has been detected in a known transiting exoplanet host star. WASP-2b; It has celestial coordinates of RA (J2000): 20h 30m 54.12s and Dec(J2000): +06° 25m 46.38s, with an apparent magnitude of 11.98, an absolute magnitude of 6.19 and depth magnitude of 0.0216 (smaller the magnitude, brighter is the star). The system is located around 500 light years away, as it was selected for this project partially for its relatively short transit time (107.9 minutes). The planet is known to be a hot Jupiter type (0.83 times bigger than the sun) and is orbiting very close to the star, as its surface temperature is about 1300 ± 54 kelvins. Significantly, it appears that WASP-2b trajectory around a host star in a retrograde direction. Moreover, gyration of WASP-2b is being affected by the huge oblateness of the star, effects of general relativity and precession.

Data Collection and Reductions of Data to produce the Light curve➔(a and b)

All the data was gathered via the 60 cm (24 in) Cassegrain reflector telescope at the York University Observatory. STXL camera has been used to collect the data as it devoted to the CCD camera. ***Unfortunately***, data derivation couldn't occur due to weather condition as we reached the last step of the checklist, but the clouds were a hindrance for this project. So, we have assumed that the data was taken on October 30th, 2018 on a distinct night. To be able to observe, first the coordinates were processed to J2018 coordinates using ETD (exoplanet transit database) and using the Digitized Sky Survey (DSS) to obtain the data for our bull's eye WASP-2. As you can see in the "appendix" the steps for observations, observation log and the star chart. Additionally, we would like to make sure the hour angle is accurate while observing, so the telescope doesn't run into the mount when the observing was predictable to be ended after the end of the transit processing. The CCD was cooled to -10° C and a series of 75 bias frames (*Bias is the term used to describe a CCD camera's pixel-to-pixel variation in zero-point. Each pixel has a slightly different base value, and this bias is removed using a bias frame* **[1])** were taken. So, at 11:00 PM Toronto local time, we located Deneb (*Deneb or* ***Alpha Cygni*** *(Alp Cyg) is the brightest* ***naked*** *eye star in the constellation* ***Cygnus****. With an apparent magnitude of 1.25v, Deneb is the 19th brightest star in the entire sky. Its absolute magnitude is -8.73 and its distance is 3230 light years* **[2])** by eye so then we can make certain that the coordinates were standardize or examine (accurate data). At 12:00 AM, we placed the telescope towards our goal, WASP-2. With an exposure of 100 seconds and a series of 250 images. The shut down was set at 3:00 AM, as we need around 15 to 30 minutes before the end of transit process.

<u>Reduction of Data (a and b)</u> ➔

In order to reduce the data, we used IRAF (*IRAF is a collection of software written at the National Optical Astronomy Observatory geared towards the reduction of astronomical images in pixel array form* **[3]**). We began to combine and collect all the biases and then outline the average of them in a frame. Thereafter, the result of the average biases frame will be withdrawing from the main set of the frames, to make sure all the flats that were taken are corrected. (*a* **bias frame** *is an image obtained from an opto-electronic image sensor, with no actual exposure time* **[4]**). Now, we need to use the average sigma clip (uncombine feature from IRAF) (*sigma clip option offered by this task; it provides for the final image a mean identical to a ``median'' option, but with a standard deviation better by 10%-15%. The average sigma clip algorithm works as followings: a mean and a standard deviation value are computed for each image pixel from the set of images, after rejecting the minimum and maximum values, then pixels which values are more than X (X~3) times the standard deviation are rejected, and a final mean value is computed, The* ***Median*** *option provides an online capability for a fast and accurate combine algorithm for image sequences***[5]**). All the flats were combined and then we applied the sigma clip, from this selection we can govern the accurate value for the mean pixel. Master flat has been formed by dividing (the bias − average light frame) by the value of the mean pixel. With the intention of obtain an accurate data of the pixel disparity, we divide the light frame by master flat. But we had an issue with the cosmic rays, as we solved by enchanting several a flat image and create the master flat also by captivating the set of the median. The withdrawal was only functional on the light frames or flat frames, as the CCD was programmed to neglect dark flat or dark current. The reduction log is provided as we can see here

<u>(Execution of Procedure) (a and b)➔</u>

1) File renamed to .fit
2) Anomalies in data has been found in the image header (*anomalies are patterns in the data that do not conform to a well-defined notion of normal behaviour* **[6]**), solved by using HTM and detect the errors
3) Modifying the image frame in DS9 (*ds9 has the capability to create an RGB image and interactively adjust many of its parameters to achieve optimal display results* **[7]**)
4) Combine all the 75 bias frames and take the average of them
5) Create one file combine all the bias frames. This will make the operation much easier to be performed and do the reduction.
6) Create a file for dark frames (but we know already that the CCD or the STXL camera has neglected the dark current, just a few data would be noticed for the dark frames)
7) Bias frame detracts from flat frames ➔ one file for the accurate flats and combine them.
8) Locate all the middling pixel value (usually = 1) from the image header
9) Create the final master flat ($\frac{\text{average flat}}{average\ pixel\ value}$)
10) Produce one file for light frames➔

    $(Average\ bias - bias\ frame)\ from\ the\ total\ light\ frame$

    ➔from this you can make a file only for corrected bias lights
11) ($\frac{\text{corrected bias lights}}{flat\ field}$)
12) Via imexamine feature in IRAF (*The imexamine task provides some of the most powerful diagnostic quick-look tools within IRAF. If an image that you wish to examine is already*

displayed in the ximtool window, simply type ***imexamine****. Wait patiently without moving the mouse and a blinking, round cursor will appear on the display. Place the cursor over a star, and strike the* ***r*** *key, and you will be presented with a radial plot of the star, along with the values of a fit to the stellar profile* **[8]**)

13) Due to the gyration of the telescope and dome we had around 35 unstable images. And the rest of the 215 images were determined as a stable data.

14) After obtaining the 215 images, we placed them into a file "stable.txt"

Analysis of Light curve to obtain planetary radius

We were looking for a signal to a noise ratio (considering as a high accurate data). So, based on the graph of the light curve➔

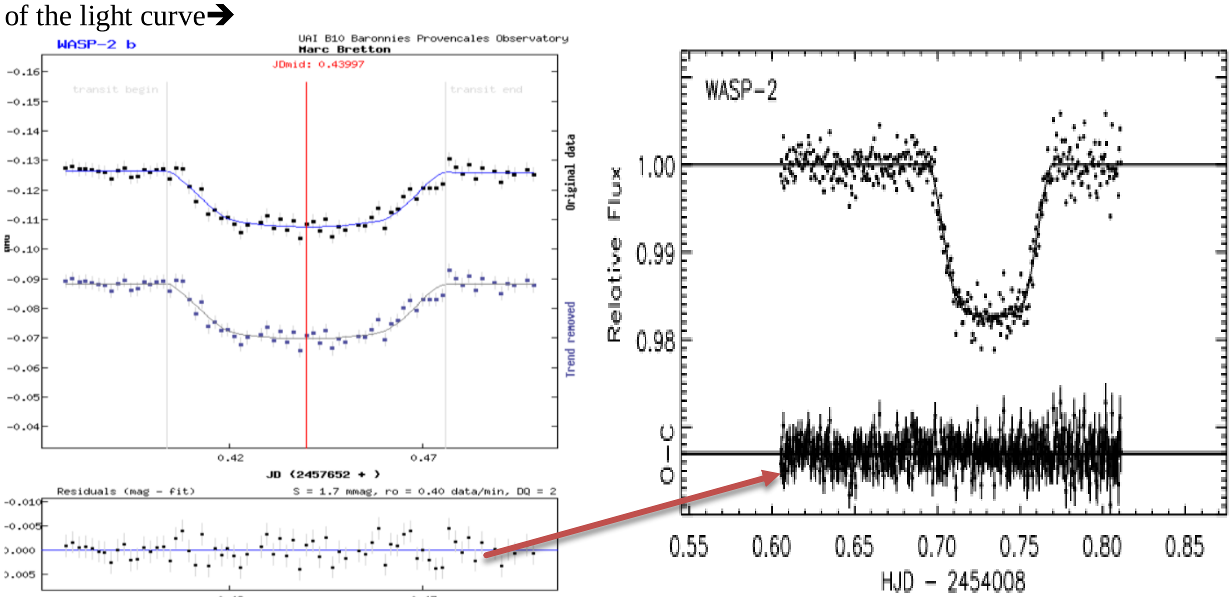


Figure (1)

Due to the low rate of the signal to noise ratio, the points initiated to scatter significantly. And this is occurred due to multi factors. For instance, light pollution (known as miasma), mist and haze. Noticeably, during the transit process, most or some of the values of the observations drop out and we can measure that by using a technique calling the differential magnitude. *This* *technique is simply the difference between the instrument* ***magnitude*** *of the target object and the comparison object (ΔMag = C Mag – T Mag)* **[9]**. And it found out that the value is more than the standard error of measurements (*SEM; estimates how repeated measures of a person on the same instrument tend to be distributed around his or her "true" score* **[10]**). Moreover, the light curve of WASP-2 is completely a self-governing data (*or Variation independent parameterizations of multivariate categorical distribution*) and that occurs when there is no similarity in the magnitude dip during the transit period between the WASP-2 and WASP-2b. Overall, the corrections of the star measurement (light curve gap) takes place near to the pred egress and pred ingress of the curve, as seen in figure (2).

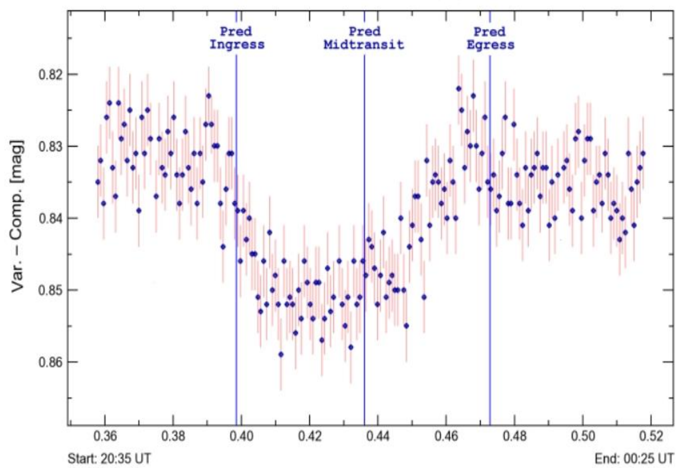


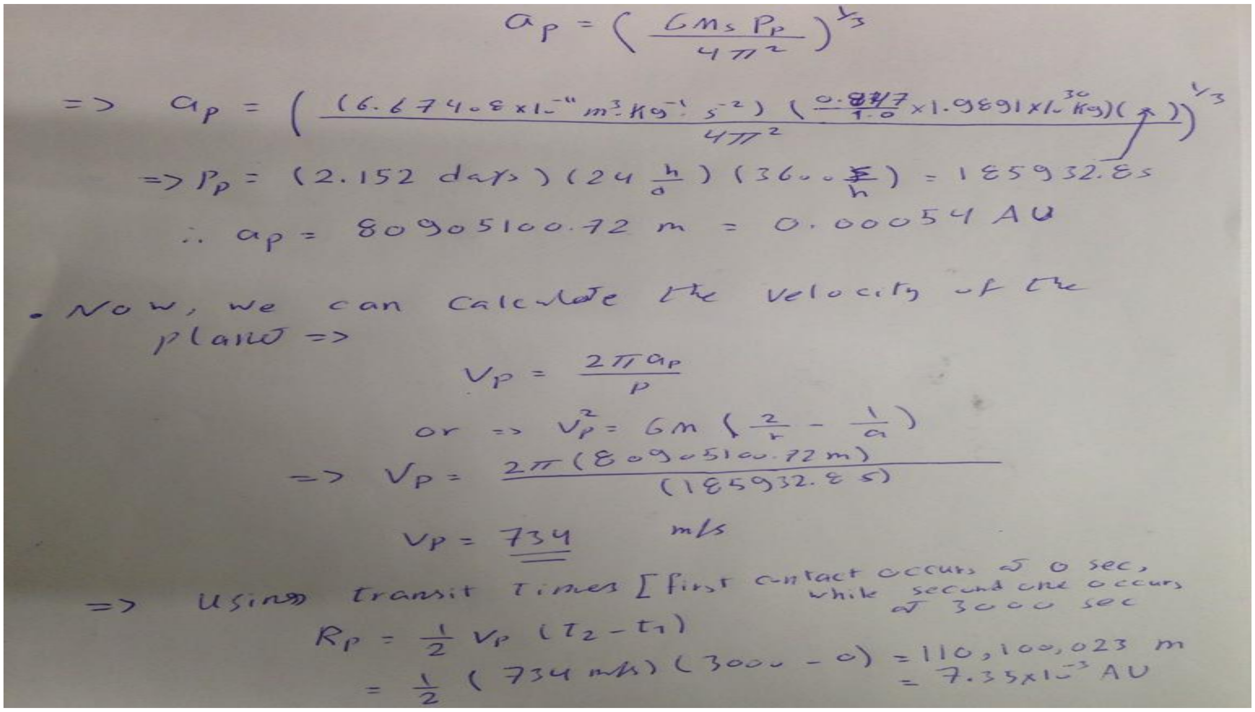
Figure (2)

Description of Planet with Reasoning and Analyses

The Description of the planet will be dependent on the semi-major axis, velocity and radius of the planet.

The WASP-2 planetary system

Companion (in order from star)	Mass	Semimajor axis (AU)	Orbital period (days)
b	0.847 (± 0.045) M_J	0.03138 (± 0.011)	2.15222144 (± 4e-07)



$$a_p = \left(\frac{G M_s P_p}{4\pi^2}\right)^{1/3}$$

$$\Rightarrow a_p = \left(\frac{(6.67408\times10^{-11}\,m^3\,kg^{-1}\,s^{-2})\left(\frac{0.8317}{1.0}\times1.9891\times10^{30}\,kg\right)(\;)}{4\pi^2}\right)^{1/3}$$

$$\Rightarrow P_p = (2.152\ days)(24\ \tfrac{h}{d})(3600\ \tfrac{s}{h}) = 185932.8\,s$$

$$\therefore a_p = 8090 5100.72\ m = 0.00054\ AU$$

• Now, we can calculate the velocity of the planet =>

$$V_p = \frac{2\pi a_p}{P}$$

$$\text{or} \Rightarrow V_p^2 = GM\left(\frac{2}{r} - \frac{1}{a}\right)$$

$$\Rightarrow V_p = \frac{2\pi(80905100.72\,m)}{(185932.8\,s)}$$

$$V_p = \underline{734}\ m/s$$

=> Using transit times [first contact occurs at 0 sec, while second one occurs at 3000 sec

$$R_p = \frac{1}{2} V_p (T_2 - T_1)$$

$$= \frac{1}{2}(734\,m/s)(3000 - 0) = 110{,}100{,}023\ m = 7.35\times10^{-3}\ AU$$

As we can see, the values don’t match with the original data of WASP-2b ((NASA’s Extragalactic Calculator). And that means we need to support our values with radial velocity method and gravitational lensing to obtain the right data for the mass.

Discussion of Uncertainties➔

Due to signal to noise ratio, temperature variations, light pollution and components accuracy. It was hard to come up with precise data. As our value for the mass is much lager than the original data. Therefore, we need to show the percentage error based on the data that we obtained➔

$$\frac{(Calculated\ data - Expected\ data)}{(Expected\ data)} * 100\%$$

$$\frac{(7.35*10^{-3} - 5.66*10^{-12})}{(5.66*10^{-12})} * 100\% = 1.3 * 10^{11}\%$$

The value of the error is too big, over here, we need to redo our data in much better weather condition, make certain that our CCD working without any sensitivity, and making sure that our flat, bias and light images are taken in accurate way which are matched with the normalization of the original data.

Summary of Results and Conclusions➔

In conclusion, after taking the images for WASP-2b and WASP-2, we came up with varies sequences. The process of taking images for the target and obtain the transit time is time consuming. The errors that we found out occurred due to the movements of the target across the field view and images was taken in a diverse pixel. These critical errors made perturbations for each image due to the sensitivity of the pixels and brightness. Consequently, the brightness of the image pixel was not precise which made the inconsistencies in the dip of the magnitude (light curve) between WASP-2 and WASP-2b. As mentioned in the uncertainties section, we need to work on the accuracy of the components, adjusting the mount and the gear of the telescope.

Appendices ➔

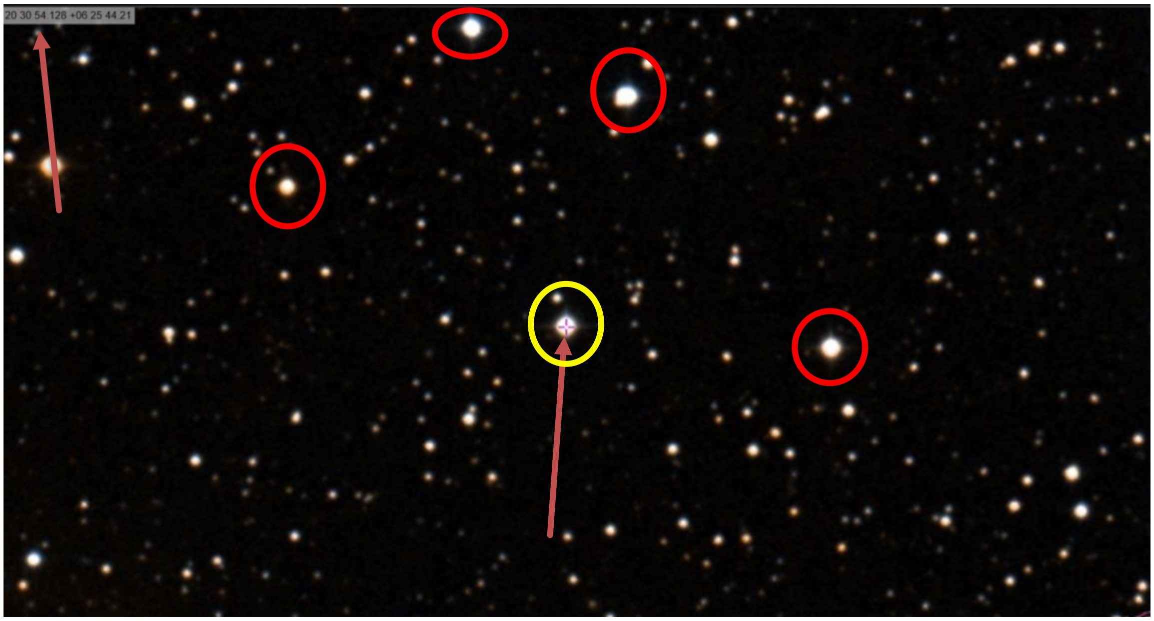


Figure (3)

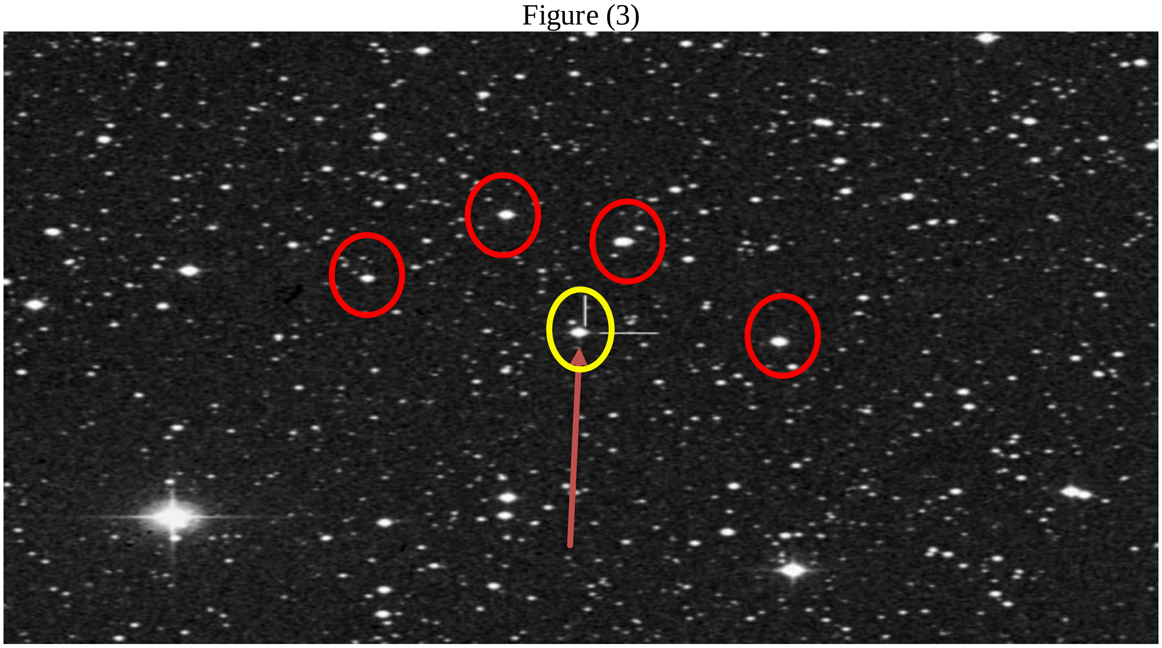


Figure (4)

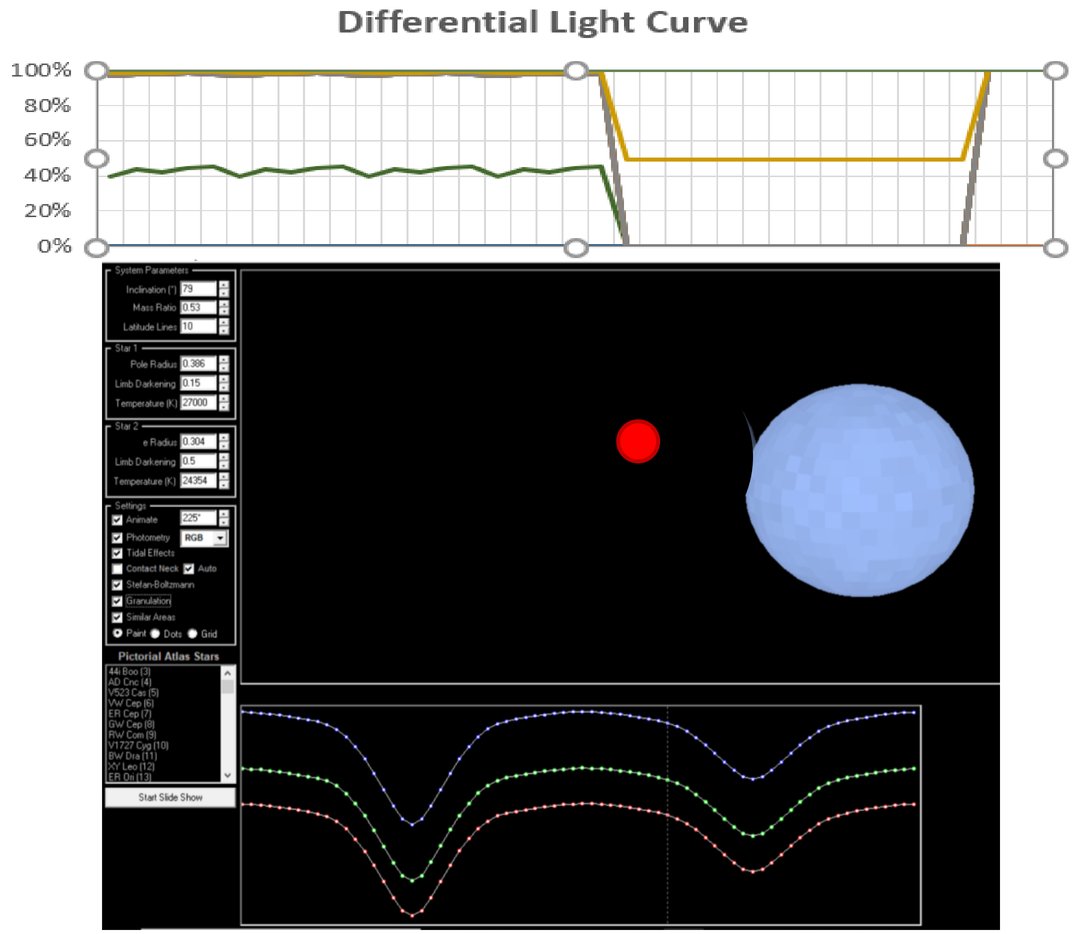


Figure (5), using a star-planet simulator software and Excel

<u>Code</u> ➔
In IRAF,

Rename * .fit

<u>Observing</u> ➔

1) Arrived at the observatory

2) Input the information for eclipse and Altair

3) Time sync is on (offset within 0.3 seconds)

4) RA motor is on (red light)

5) ST Configuration is on ➔

6) Connected to STAC6-Q and to COM-10➔ both motors are on (green and red) ➔

7) Activating limit switch (all lights now are green)

8) Closed ST configuration➔ open dome tracker

9) Connected to ARGO

10) CCD is on ➔ removed dust cover

11) Cooled CCD down to -10 degrees

12) Taking a series of 75 Bias (1*1 binning)

13) Bullseye towards Deneb➔ RA 20h 41m 26s | Dec +45° 16′ 49″ ➔ aligned via ARGO

14) Now, we targeted towards WASP-2b ➔ 20h 30m 54.12s and Dec(J2000): +06° 25m 46.38s and HA; -1h 23'

15) Series of 250 images @ 100 seconds ➔ automatically the dome will close after we determine the shutdown time.

16) Shutdown at 3 AM

<u>Observing log</u> ➔

1) 20h 30m 54.12s and Dec(J2000): +06° 25m 46.38s ➔ 20h 32m 55.12s and Dec(J2018): +06° 26m 47.38s (from J2000 to J2018)

2) Duration = 107.9 minutes, Apparent Magnitude of 11.98, Absolute Magnitude of 6.19 and Depth Magnitude of 0.0216

3) Start at ➔ 4:10 UT

4) End at ➔ 6:45 UT

5) Telescope moving within a reasonable scope (not run into mount) (adjust the hour angle➔ HA = LST-α

6) Based on the observatory location (Longitude and latitude) and Sidereal clock, we will be able to adjust the transit times (43.7735° N, 79.5019° W)

7) HA (start) = LST-α= 4:10 – 2:45 = 1.32'

8) HA (end) = LST-α= 6:45 – 2:45 = 4:45'

Data reduction while observing ➔

1) All files renamed to .fit ➔ rename *.FIT fits field=extr
2) Image header is being examined using (imhead of wasap-2b)
3) Image dimension is being changed (DS9), by using (set stdimage and imt)
4) Create average bias frame (using imcombine)
5) Create list of bias frames (*BIAS*)
6) Create list of flat frames (*FLATS*)
7) Create list of dark frames(*DARK*) ➔ imcombine @DARKLIST➔average dark frame ➔ (rejected)
8) (bias – all flat frames) @FLATLIST, dark current is not included
9) Create list of corrected flats
10) Create list of all the combine flats➔ Normalizing the flat data ➔Combine = median
11) Create list of lights➔ based on WASP light data
12) (Average bias – all lights) @LIGHTLIST and imarith
13) List of the corrected bias lights ➔ normalizing the lights data➔Using imarith
14) Using imexamine on WASP-2 and WASP-2b ➔ Create a file "stable.txt"
15) Also, we can use Excel to create a light curve as seen above in the chart stars section.

Bibliography

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(***Used this pdf file as source for how to detect an object using the transit method***)

Figures

1) [http://www.webservices.cz], W. (n.d.). Retrieved from http://var2.astro.cz/ETD/predict_detail.php?delka=43.7735&submit=submit&sirka=79.5019&STARNAME=WASP-2&PLANET=b

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