AstroLab

Differential Photometry

Introduction

Transit of Venus (Michael Cowley)

In this experiment, you will perform differential photometry on a sample of data from the Las Cumbres Observatory Telescope. Differential photometry is the measurement of changes in brightness of an object over time. In this case, you will measure the change in brightness of a distant star during an exoplanet transit event. You will compile measurements into a light curve, which will allow you to calculate various physical parameters of both the exoplanet and its host star. An exoplanet is a planet that orbits a star other than our sun. At present, it is too difficult to locate exoplanets via direct imaging. However, indirect techniques, such as the transit method, have successfully yielded thousands of detections. The transit method involves detecting the slight dip in brightness of the star, when a planet crosses in front of it, as viewed by a distant observer. Such an event is analogous to the recent transit of Venus in front of the sun (see Figure 1).

Equipment

1. Ten (10) telescope FITS images
2. Computer with Excel, AstroImageJ, and internet access

Instructions

1. From the AstroImageJ software, click on `File > Import > Image Sequence` select one of the FITS files and click on `Open`.
2. To ensure only the ten telescope images are added to your sequence, enter "`2008`" in the field `File name contains` and then click `OK`. If your computer has limited memory, you should also tick the `Use virtual stack option`. Click `OK` to proceed.
3. The new window will display your FITS image stack. If you're having trouble seeing any stars, try clicking the `Auto-Brightness and Contrast` and/or `Image Negative` buttons shown below.

AstroLab

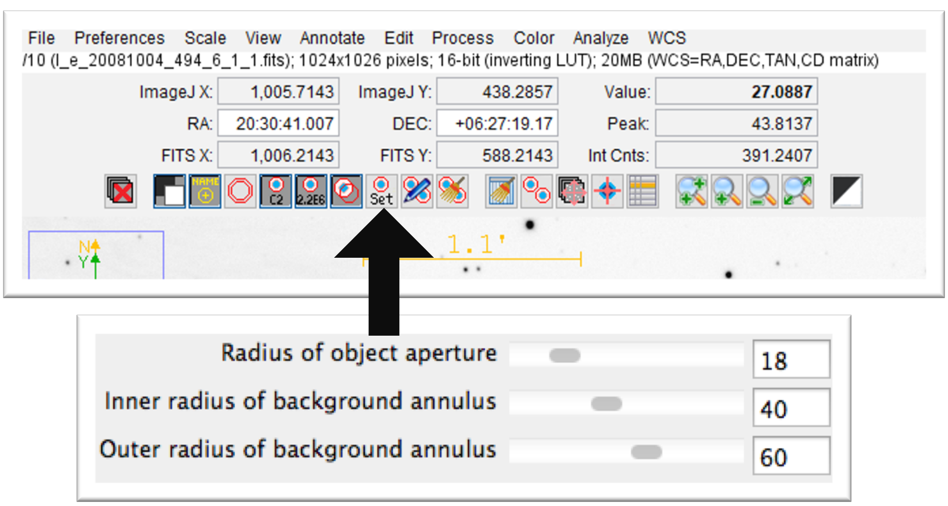
Differential Photometry

Instructions Cont.

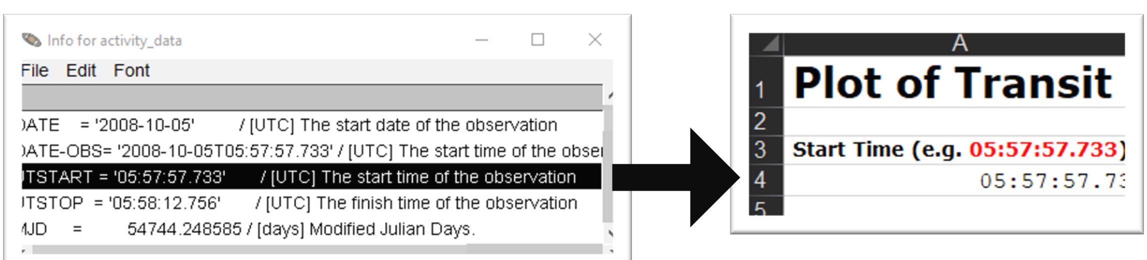
4. From the main AstroImageJ toolbar, click on `File > Open` select the `finder_chart_Wasp_2.jpg` file and compare it to the FITS image to identify the target and reference star.

Question 1: Why do you think we need a reference star?

5. From the FITS image stack window, click on the `Change Aperture Settings` button and input the values below. All other settings can be left on default.



6. From the AstroImageJ window, click on `Image > Show Info` and take note of the start time of the observation (UTSTART). As shown below, record this time, as it's exactly shown in the info box, in the first empty cell of the excel spreadsheet.

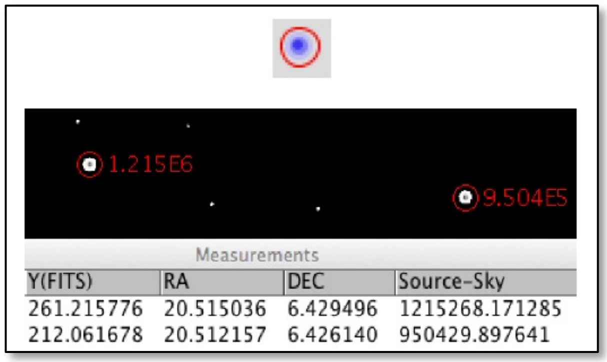


AstroLab

Differential Photometry

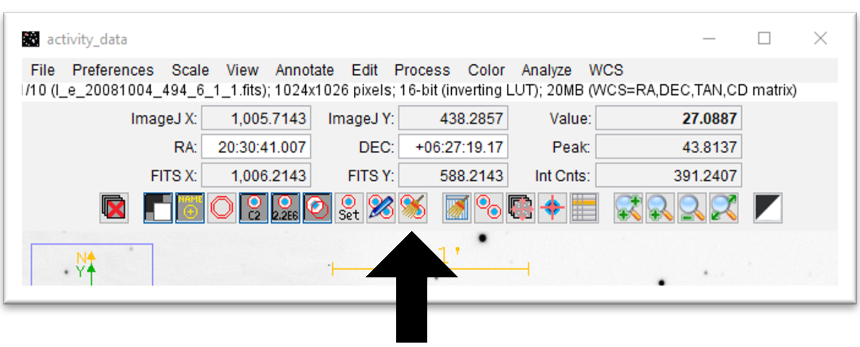
Instructions Cont.

7. From the AstroImageJ window, click on the `Aperture Photometry Tool` button and then select the target star, followed by the reference star. A new measurements window will be displayed.

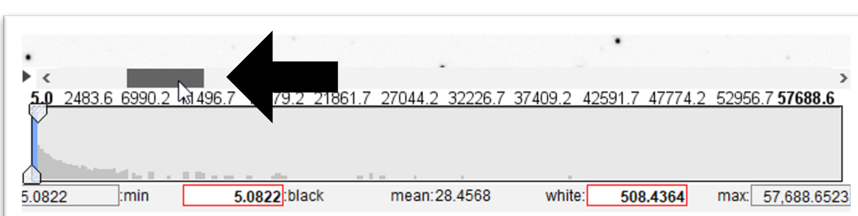


8. Record the `Source-Sky` value (the intensity) of both the target and reference star in the provided excel spreadsheet. The spreadsheet should automatically calculate the `Source / Reference` and `Relative Intensity` values. It should also plot your first data point as a red diamond.

9. Clear your aperture selections by clicking on the `Clear Apertures` button, shown below.



10. Repeat steps 6 to 9 for the remainder of the FITS frames. You can change FITS frames by dragging the scroll bar on the bottom of the image window. Remember, if you're having difficulty seeing the other FITS images, try clicking on the `Auto-Brightness and Contrast` and/or `Image Negative` buttons.



AstroLab

Differential Photometry

Instructions Cont.

Print and paste your light curve plot in the section below.

Paperless!

ASK YOUR DEMONSTRATOR TO COME PREVIEW YOUR PLOT AT YOUR COMPUTER INSTEAD!

Question 2: Discuss what is happening in your light curve plot above.

Data Analysis

For this experiment, characterising the exoplanetary system relies on the following assumptions:

1. The exoplanet is in a circular orbit
2. The exoplanet lies on an edge-on orbit (90-degree angle of inclination)
3. The stellar mass is much greater than the exoplanet's mass ($M_* \gg M_P$)
4. The semi-major axis of the orbit is much greater than the stellar radius ($d_{\text{orbit}} \gg R_*$)
5. The stellar radius is much greater than the exoplanet's radius ($R_* \gg R_P$)

AstroLab

Differential Photometry

Data Analysis Cont.

You should make use of the following formulae and data in your analysis:

$M_* = M_\odot \left(\frac{L_*}{L_\odot}\right)^{\frac{1}{4}}$	$R_* = d_{\text{orbit}} \frac{\pi t_{\text{trans}}}{T}$	Kepler's Third Law $d_{\text{orbit}} = \left(\frac{T^2 G M_*}{4\pi^2}\right)^{\frac{1}{3}}$
$R_P = R_* \sqrt{dip}$	$d_{\text{innner}}(\text{AU}) = 0.94\sqrt{\frac{L_*}{L_\odot}}$	$d_{\text{outer}}(\text{AU}) = 1.72\sqrt{\frac{L_*}{L_\odot}}$

Luminosity of the Sun, $L_\odot$	3.85×10^{26} W
Mass of the Sun, $M_\odot$	1.99×10^{30} kg
Radius of the Sun, $R_\odot$	695,700 km
Luminosity of host star, L_*	2.20×10^{26} W
Orbital Period of exoplanet, T	185,930 sec
Gravitational constant, G	6.67×10^{-11} Nm^2 kg^{-2}
Astronomical Unit, AU	1.50×10^{11} m
Radius of Jupiter, R_J	6.99×10^{7} m
Transit Time (from light curve), t_{trans}	6,480 sec
Brightness dip (from light curve), dip	2% (0.02)

Question 3: Using information from the FITS header (`Edit > FITS header...`), which telescope was used for imaging and what coordinates was it facing (right ascension and declination)?

Question 4: What is the mass of the host star, WASP 2 (M_*) in terms of the Sun's mass?

$M_* = M_\odot(L_*/L_\odot)^{\frac{1}{4}}$

AstroLab

Differential Photometry

Data Analysis Cont.

Question 5: Assuming the exoplanet WASP-2b is in a circular orbit, use Kepler's Third Law to calculate the orbital radius (d_{orbit})
$d_{\mathrm{orbit}} = (T^2 G M_* / 4\pi^2)^{\frac{1}{3}}$

Question 6: What is the radius of exoplanet's host star (R_*) in terms of the Sun's radius?
$R_* = d_{\mathrm{orbit}}(\pi t_{\mathrm{trans}}/T)$

Question 7: What is the radius of exoplanet (R_P) in terms of Jupiter's radius?
$R_P = R_* \sqrt{dip}$

Question 8: Determine the inner (d_{inner}) and outer (d_{outer}) habitable zone boundaries and comment on the habitability of the exoplanet, WASP-2b
$d_{\mathrm{innner}}(\mathrm{AU}) = 0.94\sqrt{L_*/L_\odot}$
$d_{\mathrm{outer}}(\mathrm{AU}) = 1.72\sqrt{L_*/L_\odot}$