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EXOplanet Transit Interpretation Code (EXOTIC) Instructions: How to Run the Code in the Terminal

These are the instructions for running EXOTIC to reduce your photometric data using the command-line interface terminal. **Please note:** it is recommended to run EXOTIC using our python notebook, especially if you are a new user, student, or are unfamiliar with using the command-line. The python notebook offers a much more interactive and user-friendly experience, while still running locally on your computer (you will still have access to all your files). It also makes it unnecessary to install EXOTIC and several other applications onto your computer, simplifying the setup process. However, if you are wanting to work with the command line and have successfully installed EXOTIC and its dependencies, please continue below to reduce your data using the terminal.

Please note: in order to be able to click on the links and select text in this document, you must **download it off GitHub**. The GitHub preview simply shows you an image of the document, which does not allow for those functions.

I. Using the Terminal/Ubuntu/ Windows CMD Terminal (skip this step if you are already familiar with the command line)

- Opening the Application
  - If you are using a Mac, open up the terminal.
  - If you followed the recommended installation instructions for Windows and are using Ubuntu, open Ubuntu.
  - If you chose to run EXOTIC natively on Windows, open Command Prompt.
- Changing Directories
  - A “directory” is just another term for a folder in your computer
  - To enter a directory in terminal, type “cd” followed by a space, and then the path to your directory, and then hitting return which will execute the command.
    - The path to the folder you want to change into can be found by right clicking on the folder in Finder, and then holding down the option key, and then selecting “Copy ‘Your file’ as Pathname”
    - Pasting that copied file path after the “cd” is the easiest way to accurately and reliably change into your desired directory

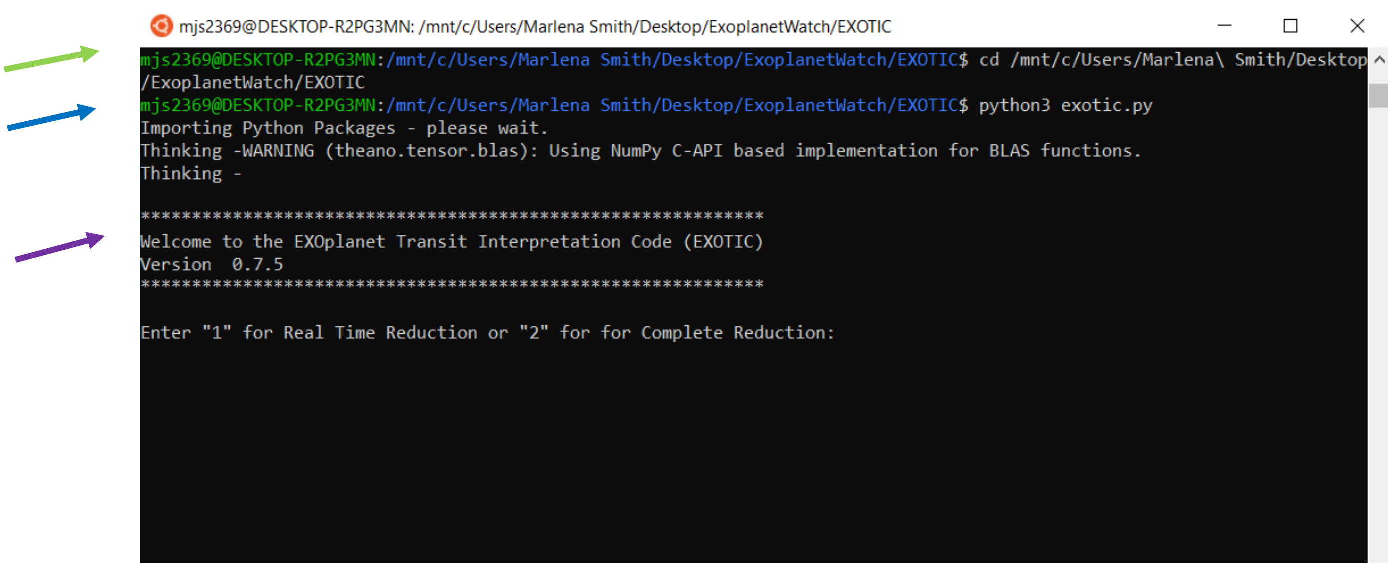
- To go back to your "Home" directory, simply type "cd", or "cd ~" for Windows CMD users and then hit enter
- "pwd" ("cd" for those using Windows CMD Terminal) can be used to determine your current directory

- Listing Files in a Directory
  - To list all of the files in your current directory, enter "ls", or "dir" for those using Windows CMD Terminal)
  - This is a good way to make sure that a/e file you are looking for is actually in the directory you think it is
- Keyboard Interrupt
  - To kill a process or program while its running, hit "Ctrl + c"
- Quitting the Terminal
  - To quit the terminal, after you have killed any processes that were running using the keyboard interrupt, type exit and hit enter

II. Getting the Code to Run

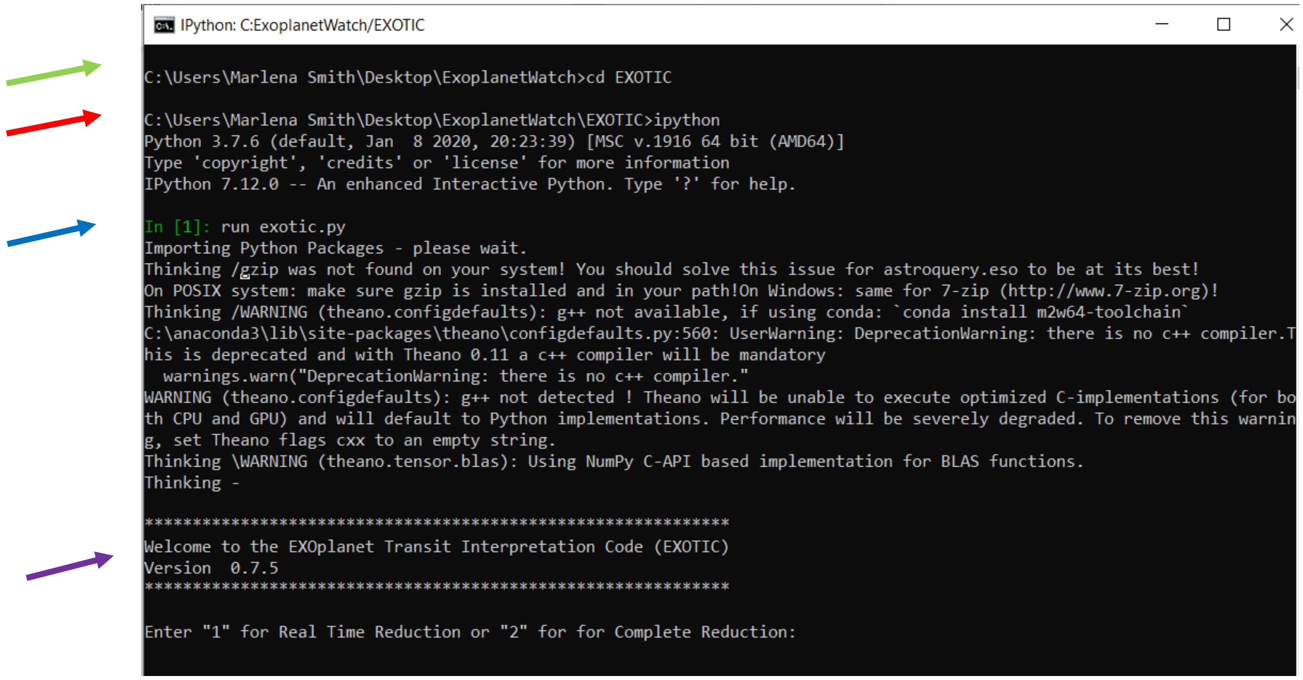
If you are using a Mac or Ubuntu:

1. Change into the base EXOTIC directory using Terminal (cd …/EXOTIC)
2. Type "python3 exotic/exotic.py" and then hit enter
   - This command may be "python exotic/exotic.py". Run this instead if command is not found.
3. If you see the EXOTIC header, the pipeline is running!



If you are using Windows CMD Terminal:

1. Change into the directory in which "exotic.py" is located using CMD Terminal
2. Type "ipython" and then hit enter
3. Type "run exotic/exotic.py" and then hit enter
4. If you see the header for EXOTIC, the pipeline is running!



After the program is running, you will first be presented with 2 options:

Enter '1' to Reduce your Data in Real Time

i. This option should only be selected if you want to a quick reduction your data while you are on an observing run
ii. This will simply serve as a visual tool, but will not fit a model lightcurve, nor will it extract planetary data

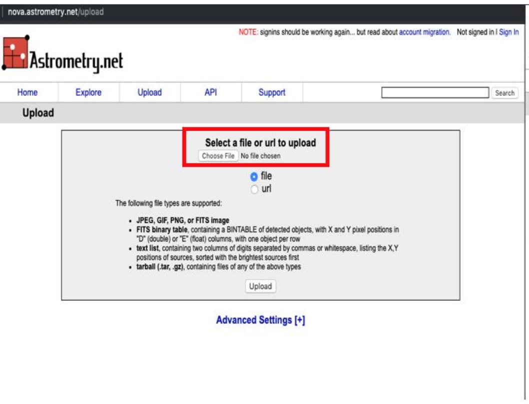
Enter '2' to do a Complete Reduction

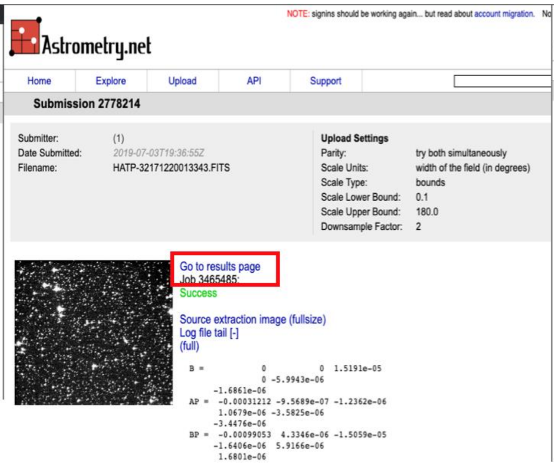
iii. The default option that should be selected at all times except for the case described above in i.
iv. This performs a full reduction on all of your data
    1. See How it Works for an explanation of the reduction process

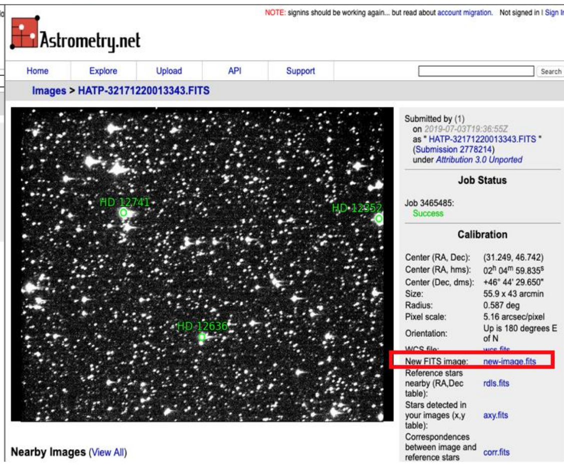
III. Real Time Reduction Routine (skip this if you entered "2")

Now that you have the pipeline running, this chapter will walk you through how to reduce your dataset in real time. The photos used below are using an example data set of HAT-P-32b.

1. Enter the directory path to the FITS Image Files
    a. You will need to enter the complete path to the folder where the images you will be taking will get saved into
        i. If you don’t have a folder in which your images will get saved, you will need to make one by simply creating a new folder using finder
    b. The easiest way to get the path to your folder is by right clicking on the folder in Finder, and then holding down the option key, selecting “Copy ‘Your file’ as Pathname”, and then pasting that into the terminal
2. Enter the name of the planet you are observing
    a. For plot title only
3. Start Your Observing Run
    a. Once you start your observing run, “.FITS” files should be entering the directory at the rate you set your observing cadence to.
4. Type “continue” after the first image has been taken and saved after the prompt
5. Entering the Pixel Coordinates of your Target Star
    a. Go to: http://nova.astrometry.net/upload
    b. Upload the first “.FITS” image in your in your dataset to Astrometry.net (left)
    c. After it finishes analyzing your image click “Go to results page” (center)
    d. Then click to download “new-image.fits” (right)







    e. Open “new-image.fits” in DS9, which should now be WCS encoded
        i. To open a fits image with DS9, simply right click on the image in Finder, and select “Open With” and choose “SAOImageDS9”
        ii. When opening for the first time, the system will say the application is by an unidentified developer. To get past this, open System Preferences and under the General pane of the Security & Privacy tab, you can allow the application under “Allow apps downloaded from:”
        iii. Here is the User Guide: DS9 User Guide on their website

    f. Search the SIMBAD database for your target star by typing its name into the search box
        i. Link: SIMBAD Search Portal

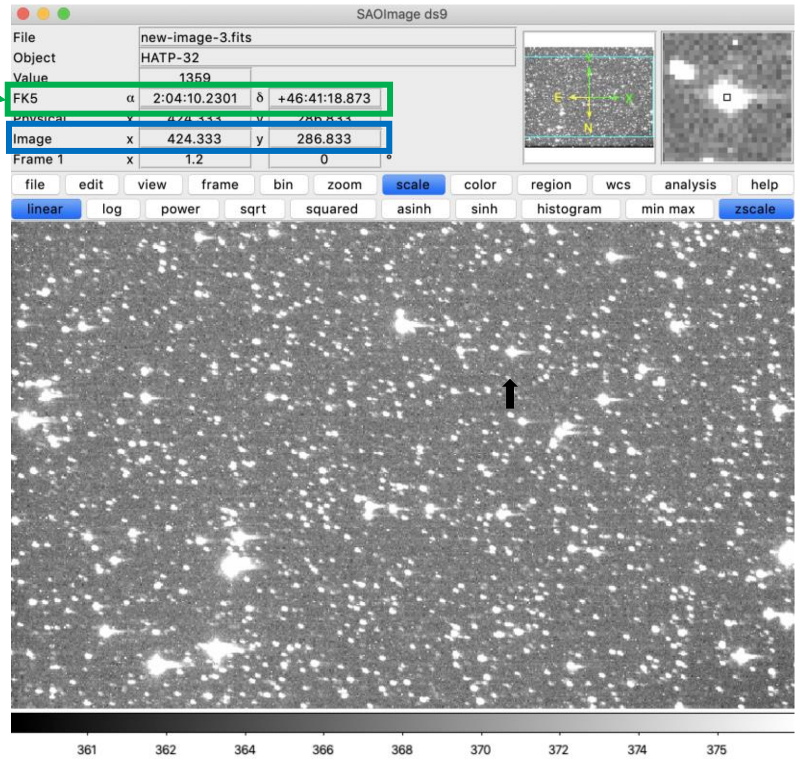
ii. Once you see a page like this one, with your target name, obtain the RA and Dec Coordinates (Green Box) and note the V-mag (Orange Box)

g. Find your target on the “new-image.fits” in DS9 by moving your cursor around on the image until the “fk5” values match the Ra and Dec values shown on the SIMBAD Database

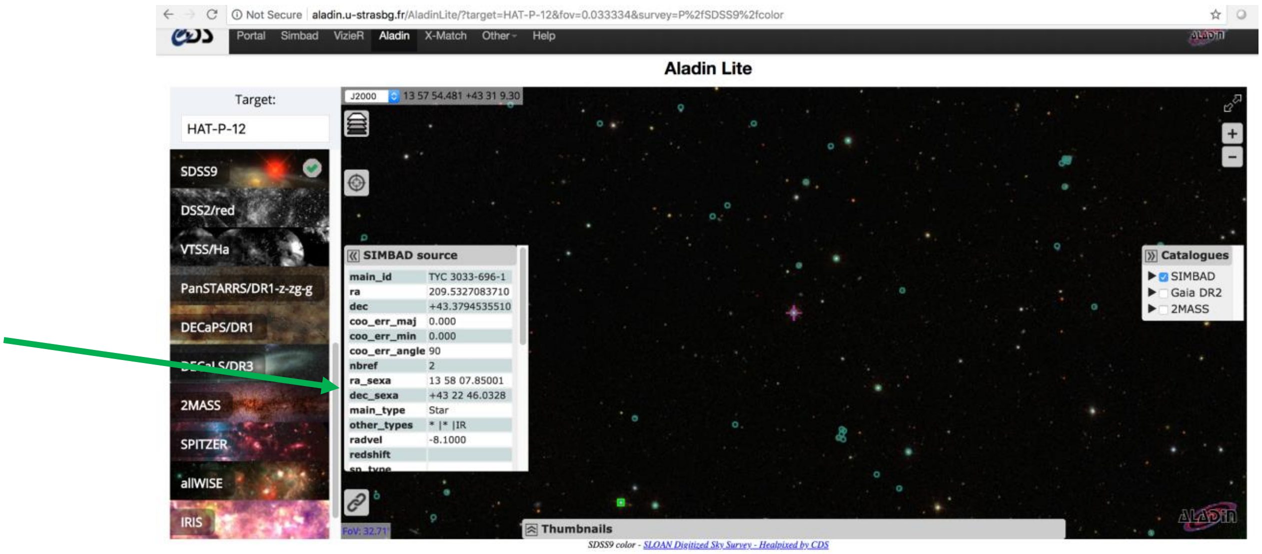
i. You can see stars more clearly by clicking “scale” → “zscale”

h. When the FK5 values match the RA and Dec from Simbad, the numbers in the boxes next to image (blue box) are the x and y pixel coordinates of your target

Move your cursor around the image (right) until your RA and Dec shown on the green box on the image match the values on SIMBAD



6. Entering the Pixel Coordinates of your Comparison Star
    a. Return to the SIMBAD Page of your Star
    b. Above the image of your target on SIMBAD, click on the "Interactive AladinLite View"
    c. Check the box that says SIMBAD under "Catalogues"
    d. Then click on the nearby stars (green circles) around your target star (purple +), looking for stars of similar brightness
    e. Then in the "SIMBAD source" box on the left, check to make sure you have in fact clicked on a star by ensuring "main_type" = Star
    f. Then scroll down in the "SIMBAD source" box and check the number next to V. If it is close to the V-mag of your target star (within 1.5 units), you have likely found a good comparison star!
    g. Obtain the "ra_sexa" and "dec_sexa" which are located in the "SIMBAD source" box (green arrow)
        i. These are the RA and Dec values for your comp star



  h. Find your comparison star on your “new-image.fits” in DS9 using the same procedure you did for finding your target star. (step 4h)
  i. Enter the X and Y coordinates of your comparison star into your terminal.
7. A plot of Normalized Flux vs. Time (a lightcurve!) will be generated, and this plot will get updated every time a new image is added to the specified folder.
8. After you are done observing, either close out the plot, or quit the program by typing “Ctrl+c”

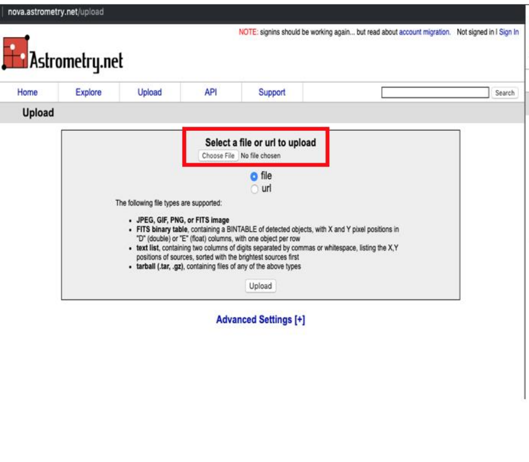
IV. Complete Reduction Routine

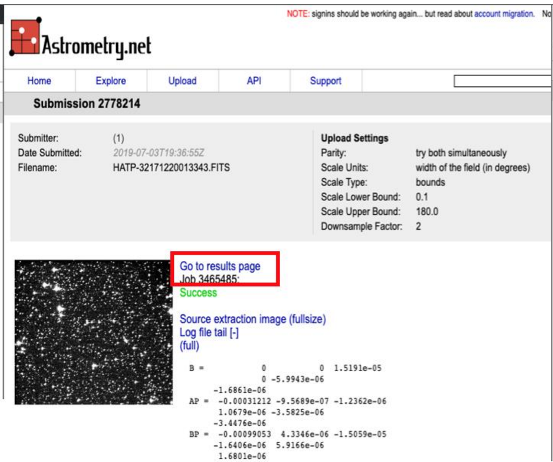
Now that you have the pipeline running, this chapter will walk you through how to perform a full reduction of your dataset. The photos used below are using an example data set of HAT-P-32b, which can be found in the sample-data folder.

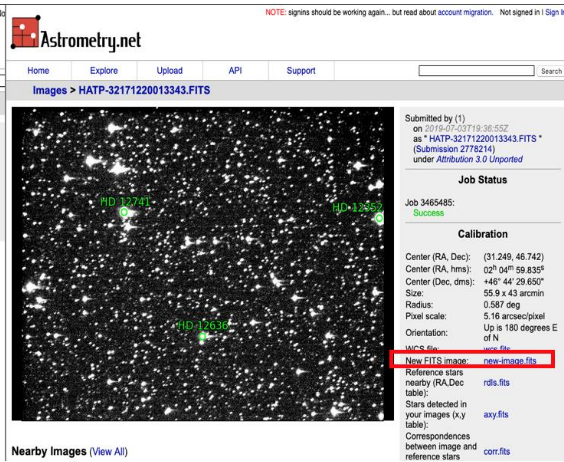
1. You will first be asked whether you will be using .FITS files or pre-reduced data in a .txt file.
   a. If you are unsure of which one you are using, you will most likely be using .FITS files (these files contain raw data obtained directly from your telescope).
   b. Type the correct number and press enter.
2. You will then be asked how you would like to input your initial parameters.
   a. Enter “1” to do so manually and **follow steps 3-15 below.**
   b. Enter “2” to do so using an input file, which is a file that contains all the parameters EXOTIC will ask for, including the location of your data.
      i. Enter the directory and filename of the input file. Hit enter.
      ii. If you select this option, **skip to step 11 below. Please note** that it may be helpful to read through those steps if you are unsure where to locate the values to enter into your input file.

        iii. You can test this method by using the file in your EXOTIC folder titled “inits.txt”. This input file contains the figures for the star HAT-P-32b, which corresponds to the sample data.
        iv. Similarly, to quickly create an input file and therefore bypass entering the data manually, make a copy of the file ‘inits.json’ (this is the input file for the sample data on HAT-P-32 b) in the main EXOTIC directory. Then, simply replace the values with those for your own data.
            1. If you are the values of any of the parameters, you can leave those blank. As will be shown later in the instructions, all of the values in your input file will be compared to those published in the Exoplanet Archive for your planet. You will be able to choose to lsuse these values as well.

3. Enter the directory path to the FITS Image Files
    a. You will need to enter the complete path to the folder where the images you want to reduce are located
    b. The easiest way to get the path to your folder is by right clicking on the folder in Finder, and then holding down the option key, selecting “Copy ‘Your file’ as Pathname”, and then pasting that into the terminal
4. Enter the directory path to the folder you want the results of the reduction saved into
    a. If you don’t already have a folder where you want your results saved into, you can create a new one by typing ‘new’ and entering a name for it. This new folder will be placed in the base EXOTIC directory.
5. Enter the name of the planet you are looking at and then the date (MM-DD-YYYY)
    a. You will need to make sure the formatting of the planet name is the same as in the Exoplanet Archive: https://exoplanetarchive.ipac.caltech.edu/index.html
6. Enter the longitude and latitude in degrees of where you observed when prompted
    a. These values are easy to find by simply googling it (an estimate is sufficient)
7. Enter the elevation (in meters) of your observation location (can be an estimate)
8. Locate Your Target Star
    a. Go to: http://nova.astrometry.net/upload
    b. Upload the first “.FITS” image in your in your dataset to Astrometry.net (left)
    c. After it finishes analyzing your image click “Go to results page” (center)
        i. If the results shown in the figures do not appear, refresh the page.
    d. Then click to download “new-image.fits” (right)







e. Open “new-image.fits” in DS9, which should now be WCS encoded. This means that the image’s pixel coordinates have been mapped to their celestial coordinates (right ascension and declination), so that each pixel is now representative of a location in space. This is also known as a plate solution.

   i. One way to check is if the boxes next to the FK5 label in DS9 are no longer empty once you hover your cursor over the image

f. Search the SIMBAD database for your target star by typing its name into the search box

   i. Link: [SIMBAD Search Portal]()

   ii. Use the name formatting from the source tweet

g. Once you see a page like this one, with your target name, obtain the RA and Dec Coordinates (Green Box) and note the V-mag (Orange Box)

h. Enter the RA and Dec in the form ‘##:##:##’

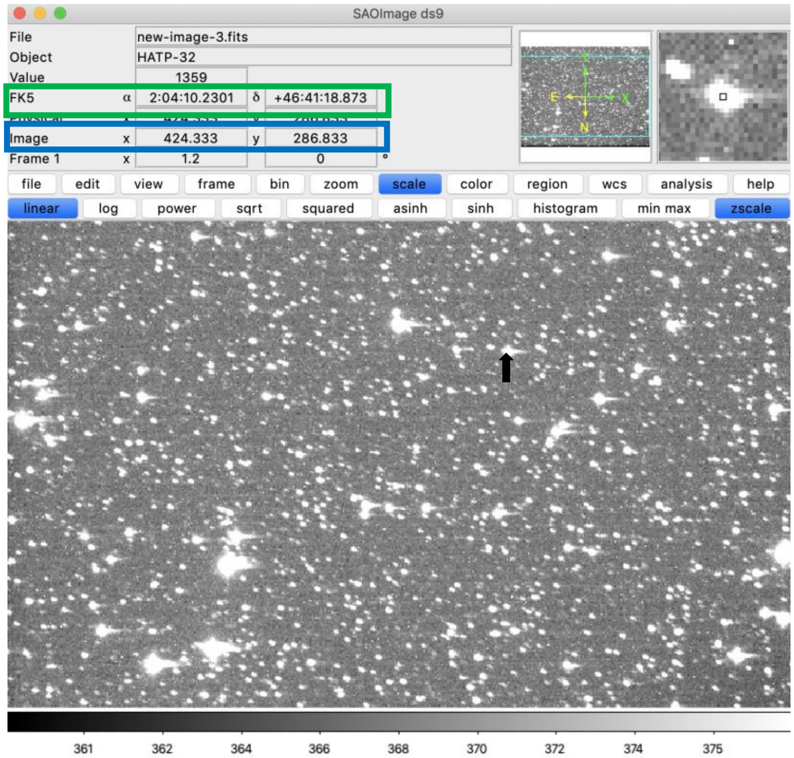
   i. For example, in the example above, the RA should get entered as 02:04:10 and the Dec as 46:41:16 (ignore the values after the decimal).

i. Find your target on the “new-image.fits” in DS9 by moving your cursor around on the image until the “fk5” values match the RA and Dec values shown on the SIMBAD Database

   i. You can see stars more clearly by clicking “scale” → “zscale”. See the blue highlighted buttons in image below.

ii. When the FK5 values match the RA and Dec from Simbad, the numbers in the boxes next to Image (shown in the blue box below) are the x and y pixel coordinates of your target

Move your cursor around the image (right) until your RA and Dec shown on the green box on the image match the values on SIMBAD



j. Enter the Target X and Y Image (pixel) position (Blue Box in image above) into the terminal when prompted.

9. Decide how many comparison stars you want to use
   a. 3 is recommended, but any number between 1-10 will do
10. Enter the X and Y Pixel Coordinates of your Comparison Stars:
   a. Return to the SIMBAD Page of your Star
   b. Above the image of your target on SIMBAD, click on the "Interactive AladinLite View" (highlighted in red below).

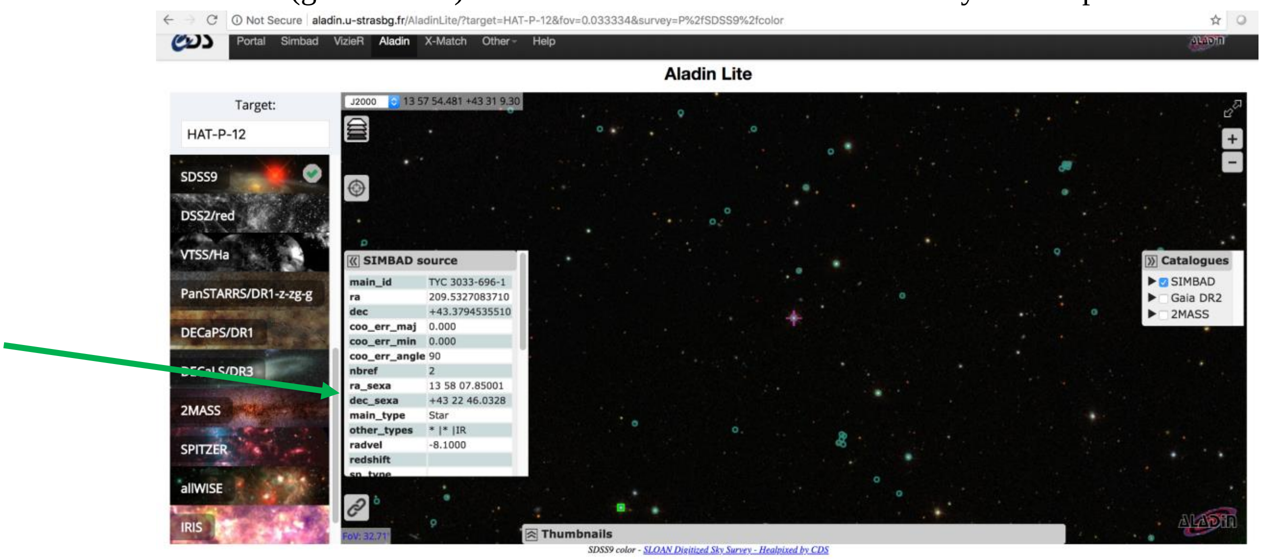
c. Check the box that says SIMBAD under “Catalogues”

d. Then click on the nearby stars (green circles) around your target star (purple +), looking for stars of **similar brightness**

e. Then in the “SIMBAD source” box on the left, check to make sure you have in fact clicked on a star by ensuring “main_type” = Star

f. Then scroll down in the “SIMBAD source” box and check the number next to V. If it is close to the V-mag of your target star, you have likely found a good comparison star!

g. Obtain the “ra_sexa” and “dec_sexa” which are located in the “SIMBAD source” box (green arrow). These are the RA and Dec values for your comp star



h. Find your comparison star on your “new-image.fits” in DS9 using the same procedure you did for finding your target star. (step 8i)

i. Enter the X and Y coordinates of your comparison star into your terminal.

j. Repeat steps 10b through 10j until you have entered the coordinates for the number of comparison stars you wanted to use

11. When asked if you have calibration images (flats, darks, or biases), enter ‘y’ if you have them, otherwise enter ‘n’
    a. If you don’t know, or aren’t sure what they are, you probably don’t have them and should enter ‘n’ and the code will take you to step 8.
    b. For each type of calibration image you have, enter the directory path to where each set located when prompted
12. Enter your AAVSO observer account number & secondary observer codes
    a. If you do not have these, or are unsure, you can type N/A.
13. Enter your camera type.
14. Enter the pixel binning – this is the process in which adjacent pixels are combined into one, averaging the brightness values across them. This reduces noise by increasing the signal-to-noise ratio in digital cameras. If you are unsure of this value, simply enter “1x1”

15. Enter the planetary parameters for lightcurve fitting:
    a. First, EXOTIC will compare the values you inputted with those obtained from the NASA Exoplanet Archive. For each value, if your input does not match up with those on the Exoplanet Archive, you will be given the option to use the value you already inputted, the value from the Exoplanet Archive, or enter a new value. Typically, you will want to choose the value offered by the Exoplanet Archive.
    b. Go to the NASA Exoplanet Archive look up
        i. Link: NASA Exoplanet Archive Search
    c. Enter the name of your target star in the search bar under "Host Name" then click on its name once you have found it
        i. The site is case sensitive so be careful with capitalization
        ii. It should open a site that looks like the image shown on the next page
    d. You will be prompted to verify that the values obtained for each parameter match up with the values published on the Exoplanet Archive's website.
        i. Parameters: Orbital Period, Mid-Transit Time, Eccentricity, Ratio of Planet to Stellar Radius, Ratio of Distance to Stellar Radius, Orbital Inclination (all boxed in green in the image above), etc. These parameters are also listed in the Glossary, located in the Documentation folder.
        ii. For Mid-Transit Time, you want to pick the largest value in the column and its corresponding uncertainty (the values after the ±).
        iii. For everything else, pick the value highlighted in gold if it's available, and then go to the most recently published non-null value if not.

NASA Exoplanet Archive Links					
Planet	Related Overviews				Transit Service
	Confirmed		Kepler Pipeline		
HAT-P-32 b	Planet	Host			HAT-P-32 b Transits

Planet Orbital Properties

Planet	Period (days)	Semi-Major Axis (AU)	Inclination (deg)	Eccentricity	Time of Periastron Passage (days)	Longitude of Periastron (deg)	Date of Orbital Solution	Reference
b	2.15000825±0.00000012	$0.03427^{+0.00040}_{-0.00042}$	88.90±0.40	<0.044	null	null	null	Bonomo et al. 2017
b	2.150010±0.000001	null	88.90±0.40	0.0	null	null	null	Stassun et al. 2017
b	2.1500080	null	$89.33^{+0.58}_{-0.80}$	0	null	null	null	Nortmann et al. 2016
b	$2.15000805^{+0.00000093}_{-0.00000097}$	0.0343±0.0004	88.9±0.4	$0.0072^{+0.0700}_{-0.0064}$	null	$96^{+180.0}_{-11}$	null	Zhao et al. 2014
b	null	null	null	$0.20^{+0.19}_{-0.13}$	null	$58.0^{+28.0}_{-53.0}$	null	Knutson et al. 2014
b	2.1500085±0.0000002	null	$89.12^{+0.61}_{-0.68}$	null	null	null	null	Gibson et al. 2013
b	2.150008±0.000001	0.0343±0.0004	88.9±0.4	0.	null	0	null	Hartman et al. 2011

Planet Parameters

Planet	M sin(i)		Mass		Radius			Density	Equilibrium Temperature	Reference
	(Jupiter Mass)	(Earth Mass)	(Jupiter Mass)	(Earth Mass)	(Solar Radii)	(Jupiter Radii)	(Earth Radii)	(g/cm^3)	(K)	
b	null	null	0.75±0.13	238±41	0.1838±0.0026	1.789±0.025	20.05±0.28	$0.163^{+0.029}_{-0.028}$	null	Bonomo et al. 2017
b	null	null	0.830±0.210	264±67	0.180±0.014	1.75±0.14	19.6±1.6	null	null	Stassun et al. 2017
b	null	null	null	null	null	null	null	null	null	Nortmann et al. 2016
b	null	null	null	null	0.184±0.003	1.789±0.025	20.053±0.280	null	null	Zhao et al. 2014
b	null	null	0.79±0.15	251±48	null	null	null	null	null	Knutson et al. 2014
b	null	null	0.8600±0.1640	273.3±52.1	$0.1845^{+0.0029}_{-0.0028}$	$1.796^{+0.028}_{-0.027}$	$20.13^{+0.31}_{-0.30}$	0.18±0.04	1779±26	Gibson et al. 2013
b	null	null	0.860±0.164	273.322±52.122	0.1839±0.0026	1.789±0.025	20.053±0.280	0.19±0.04	1786±26	Hartman et al. 2011

Planet Transit Properties

Planet	Depth (perc)	Duration (days)	Duration (hours)	Mid-Point (days)	Impact Parameter	Occultation Depth (perc)	Ratio of Distance to Stellar Radius	Ratio of Planet to Stellar Radius	Reference
b	null	null	null	2454420.44645±0.00009	null	null	null	null	Bonomo et al. 2017
b	2.300±0.012	null	null	null	null	null	6.06±0.13	null	Stassun et al. 2017
b	null	null	null	2456185.602987±0.000110	null	null	$6.123^{+0.021}_{-0.054}$	$0.1516376^{+0.0008740}_{-0.0005450}$	Nortmann et al. 2016
b	null	null	null	$2454420.44712^{+0.000092}_{-0.000084}$	null	null	null	null	Zhao et al. 2014
b	null	null	null	null	null	null	null	null	Knutson et al. 2014
b	null	$0.12959^{+0.00059}_{-0.00057}$	$3.1102^{+0.0142}_{-0.0137}$	2454942.898449±0.000077	$0.0930^{+0.0710}_{-0.0650}$	null	$6.091^{+0.036}_{-0.047}$	0.1515±0.0012	Gibson et al. 2013
b	1.8523	0.1295±0.0003	3.1080±0.0072	2454420.44637±0.00009	$0.117^{+0.045}_{-0.047}$	null	$6.05^{+0.03}_{-0.04}$	0.1508±0.0004	Hartman et al. 2011

16. Once this has been completed, EXOTIC should begin reducing your data and creating your lightcurve and other data products. Now all you have to do is wait! The process will likely take around 20 minutes.
17. Once the reduction process is finished, you should see the following notice:

```
*********************************************************
FINAL PLANETARY PARAMETERS

              Mid-Transit Time [BJD]: 2458107.71366 +/- 0.00091
  Radius Ratio (Planet/Star) [Rp/Rs]: 0.1531 +/- 0.003
 Semi Major Axis/ Star Radius [a/Rs]: 5.179 +/- 0.096
               Airmass coefficient 1: 7430.82 +/- 22.81
               Airmass coefficient 2: -0.1182 +/- 0.0023
                    Residual scatter: 0.57 %
*********************************************************

Final Planetary Parameters have been saved in sample-data/ as HAT-P-32 b_December 17, 2017.json

Output File Saved

************************
End of Reduction Process
************************
```

18. Congratulations! You’ve completed the reduction process. To view the results, visit the directory you entered to save the results into. For more information on how EXOTIC works and how to interpret your results, see our other guides in the Documentation folder. Happy observing!

V. Additional Command Line Arguments

In this section, we will show how to use **optional** command line arguments to run EXOTIC with different conditions. With these command line arguments, users can now use the command line to bypass obtaining the planetary parameters from the Exoplanet Archive, work with prereduced data, and instantaneously begin reducing your data as specified in an input file without any further prompts to the user.

In order to utilize this, **add** one of the following command line arguments to the end of the command “python3 exotic/exotic.py”. The final command will thus be the following (using the first option): “python3 exotic/exotic.py -i inits.json -o reduce override”. **Please note** that this command may not work if you are using another version of Python. If this is the case, replace ‘python3’ with ‘python’ in the command.

All command line arguments:

- -i inits.json -o reduce override
- -i inits.json -o prereduced override
- -i inits.json -o reduce
- -i inits.json -o prereduced
- -i inits.json

If users use the -o argument, they **must** enter 1 or more parameters. Also, you cannot enter both reduce and prereduced as that will result in an error. If override is not a given parameter, it will assume the user still wants to check between the NEA and their JSON file.

The override option will **not** scrape the NEA. Therefore, you must make sure that your input file is correct and complete beforehand.