Indoor Lab 8 - Exoplanets

Objectives: To explore some indirect astronomical observing techniques that allow to discover and characterize objects that are not easily or not at all visible. To explore astronomical time series and connect the shape of a lightcurve to physical parameters (orbital period, size). To familiarize the student with photometry, and the synergic use of multiple datasets to obtain more accurate measurements.

1 Discovering Exoplanets

A recent astronomical discovery, is that the Universe is populated by an incredibly high number of planets, in a variety of sizes and conditions. Statistically speaking, every star has a planet! Exoplanets that transit, i.e.: we see them pass in front of their star, will cause light from the star to be dimmed by a few percent, allowing us to discover the plantes, and providing critical insight on the properties of the planet. Transits tell us the size of the planet (from the dimming) and the semi-major axis of the orbit (from the duration of the transit).

In this Lab, we will use CCD images from the Faulkes Telescope North to try and detect the transit of a known extrasolar planet and practice photometric techniques. Then, an online interactive exoplanet hunter technique will be used to get a better transit for this exoplanet.

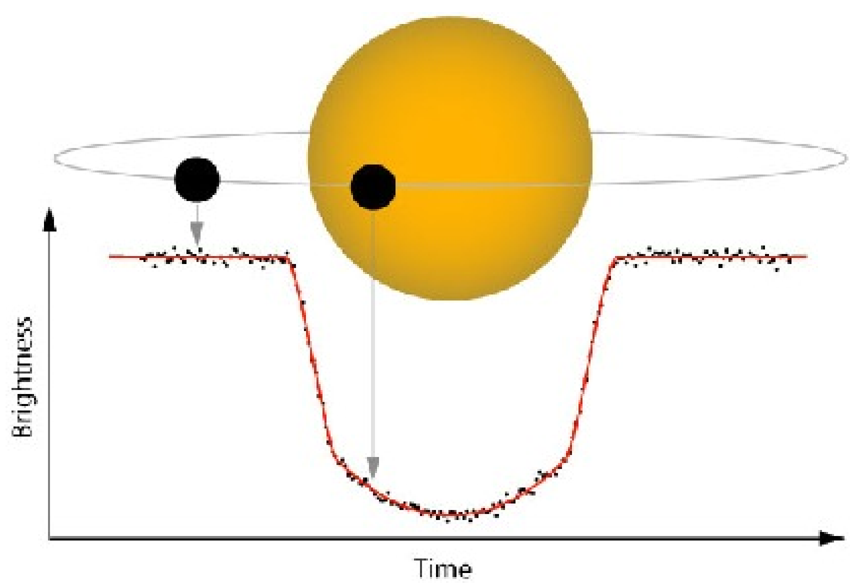

Figure 1: When the planet WASP-10b crosses the disk of its star, WASP-10, the brightness of the star decreases, allowing scientists to measure the precise size of the planet. Credit: Prof. John Johnson

2 Understanding the Transiting Technique:

If you know the mass of the star, the transit technique can give you the ratio of the radius of the star and the planet (it also provides us with the transit duration time (dt) which in turn gives us an estimate of the period of the orbit, which you can do for extra credit). If we know the stellar mass M then we can use this and the semi-major orbital radius a to estimate the ratio of the planet and star radii.

Parameter	Value
RA (J2000)	$20^h13^m31.61^s$
Dec (J2000)	$+65.0943°$
M(M.)	0.85 ± 0.03
R(R.)	0.823 ± 0.025

Table 1: Physical Parameters for Qatar-1b system

The dip in the light curve due to the transiting planet is directly related to the ratio of the area of the projected disks of the star and planet, since it is proportional to the fracion of star light that the planet blocks. the area of a circle is proportional to the square of the radius, hence the depth of the dip in the transit lightcurve will be $(R_p/R)^2$.

The orbital radius a of the planet is estimated using Keplers 3rd Law given the mass and radius of the star and the transit duration. Recall Keplers 3rd Law:

$$P^2 \propto a^3 \tag{1}$$

or in words: the period of an orbiting body and its orbit (semi major axis) are bound. If you know one, you know the other, at least for circular orbits where the proportionality constant is $4\pi^2/(GM)$. We can wait for another transit, and get the period, then we have the semi major axis. . Note however that there are ways to do this even with a single transit, if you know the radius of the star R and the inclination of the planets orbit i, by using Keplers third law and the following equation:

$$dt = \frac{P}{\pi}\sqrt{(\frac{R_*}{a})^2 - \cos^2(i)} \tag{2}$$

or if the planet is seen edge on simply: $t_{tr} = (P/\pi)(R_*/a)$, where t_{tr} is the transit duration. You should try combining the equation above with Keplers third law to derive the semi major axis of the planet when you have your Agent Exoplanet lightcurve!

You will use data from the Faulkes Telescope North for the planet Qatar-1b. Qatar-1b is the first extrasolar planet to be detected by a Qatar-led survey programme, and orbits the star 3UC311-087990 at a distance of 500 ly from Earth. Its discovery, announced on 20 December 2010, was through the transit technique and subsequently confirmed using the radial velocity method.

3 Using Agent Exoplanet

You will use an online programme called Agent Exoplanet to produce light curves of Qatar 1b. You are doing photometry on the data. In a nutshell, you will select your target star, the star hosting Qatar-1b, and measure its brightness image after image. The planet passing in front of it will cause the brightness to decrease. You will need to specify the centroid : the position of the star in the image. You will need to specify an aperture: basically the extent of the star in your image. The brightness of the pixels within the aperture will be summed to get the total brightness of the star. However there is a bright sky behind the star, so if you do not take care of that your total brightness will be overestimated (and more importantly changes that you may see rom one image to the next may not be only due to changes in the star brightness. To remove the sky from the star brightness an area around your aperture is selected, and the average sky luminosity in this area will be assumed to be the average sky luminosity underneath the star. Good news: Agent Exoplanet does this for you!!! But you should still know what is going on. Lastly: it is not sufficient to measure the brightness of your target star: changes in the registered star brightness in a CCD image may be due to many thing, not just to actual changes in the star brightness. The easiest example is if a cloud passes in fromt of your field of view: that will cause a dimming of the star. But all the stars in the field will also get dimmer accordingly! To correct for these changes in the luminosity of the stars in your image, you will select other stars, called reference stars, and measure their brightness as well. Changes in brightness that are common to all stars can then be removed (Agent Exoplanet does this for you) and what you are left with is changes that are specific to your target star. Go to: `http://lcogt.net/agentexoplanet/`. Find the Qatar-1b data set in this programme. Now you need to to click on the button Analyze images for this exoplanet (see Figure 2). You will now be asked to log into your account. If you do not already have one, simply register for one on this site and you can move straight onto using the programme. The Faulkes Telescope Dataset for Qatar-1b is vast! You will not need to analyze all the images in it. The online programme uses combined photometric measurements from many users to produce an average light curve. You can measure as many of these images as you like, because Agent Exoplanet will combine your measurements with those of other volunteers, and produce a combined result. However, make sure you do enough to obtain a decent light curve. Make sure you have read the instructions at `http://lcogt.net/agentexoplanet/briefing/`. Once you have done enough photometry, click on the lightcurve tabs to the right of the page.

You will see all of your data and the resulting light curve you have produced. This allows you to investigate your analysis and classify your light curves, including checking whether you want to remove what you believe to be "bad" sets. Carefully go through and check your measurements. If you see anything that is not a transit dip (e.g. a sharp vertical spike) then use the buttons to mark it. You can change your mind at any time, just click the relevant button. To check on the classifications you have made, click the "Toggle Table" link. You must remember that other people will see this lightcurve so make sure you do a good job with your analysis. Describe what you do with Agent Exoplanet below. You must keep a note of everything you have done in using Agent Exoplanet including the number of images you analysed and the number of stars you used in each image. Include the details for the final lightcurve produced by Agent Exoplanet and print this final lightcurve out.

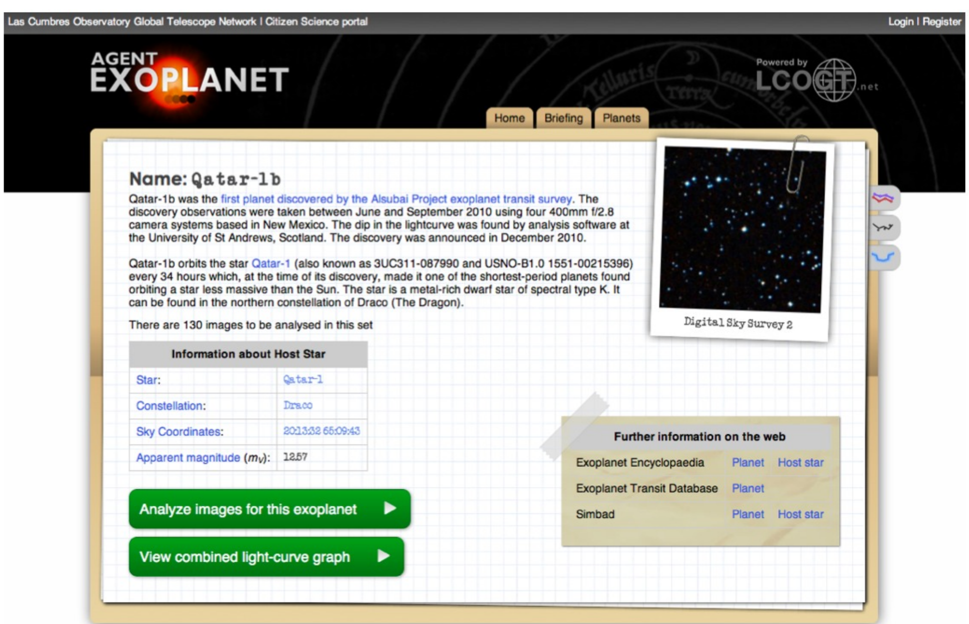

Figure 2: A screenshot of the Agent Exoplanet website with Qatar 1b dataset.

4 Getting the parameters for the planet:

When you are happy with your lightcurve, measure the relevant parameters: the duration and depth of the transit. Use the equations and star parameters provided earlier derive the radius of the planet Rp and the period P of the orbit and report them below (showing your calculation):

R_p :____

P :____

Ultimately Agent Exoplanet will produce a Master light curve from everyones data with a fitted a transit curve. Once the transit curve has been drawn, Agent Exoplanet produces a scaled cartoon of this extra-solar planetary system based on your and all other volunteers combined measurements. It will also give you the parameters which fit the light curve including the % dip in brightness, the diameter of the planet, the duration of the transit, and the ratio of planet-to-star radius. Compared them from what you found from your own lightcurve.

Questions: How close are the parameters you derive from your own lightcurve to those derived by Agent Exoplanet from the *Master* lightcurve ?

What may have caused the discrepancy?