Detecting Extrasolar Planets

An Investigative Simulation of Detection by Transit

Introduction

Since the time of the early Greeks, and possibly even before that, people have wondered if there are planets circling other stars way beyond our own solar system. As of May 2008 some two hundred and eighty seven exoplanets (or extrasolar planets as some call them) have been confirmed, with one orbiting star HD 209458 being confirmed as having water vapour in its atmosphere. None however are thought to be Earth-like. So how has this been achieved? There are a number of methods but the one you will be simulating is that of detection by the transit of such a planet across the face of the star. This is a commonly used technique and one which is to be used on the NASA *Kepler Photometer* due to be launched into orbit around the Earth in February 2009.

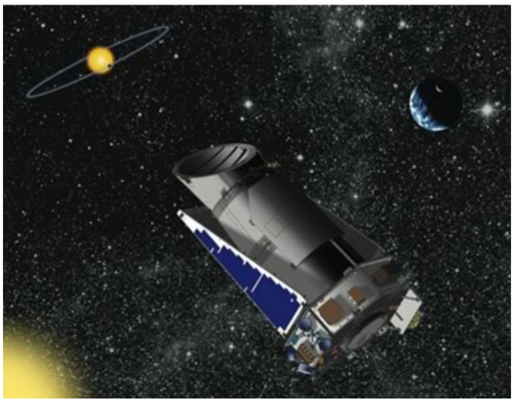

Figure 1 Artist's impression of the Kepler Photometer in orbit (Courtesy NASA)

The photometer is basically a telescope, though it is not being used to take pictures, it measures the intensity of the light received. After the light enters the instrument it undergoes some refraction at the Schmidt Corrector, then reflection from the Primary Mirror, before being incident on the array of forty-two CCD (Charged coupled device) arrays. Its structure is shown in Figure 2.

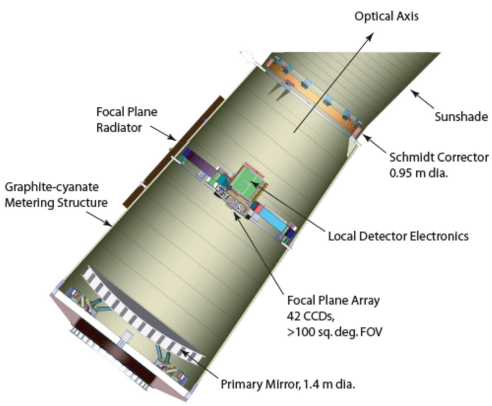

Figure 2 Structure of the Kepler Photometer

(Courtesy NASA)

How the photometer's sensors work

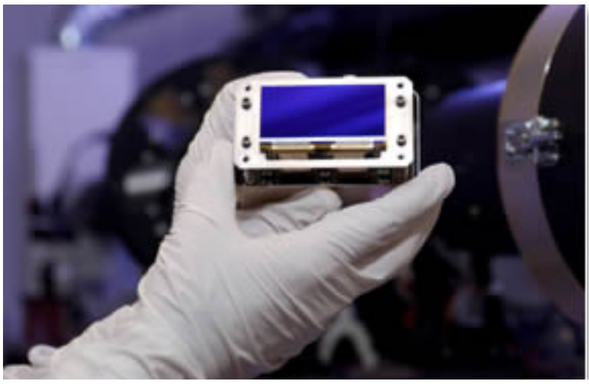

Figure 3 CCD array

The CCD array shown in Figure 3 is much like that in a digital camera except it provides 95 megapixels instead of the 4-10 commonly found on ordinary cameras. Each pixel acts like a capacitor with a solar cell attached to it. As a photon of light is absorbed so a photoelectron is released from the semiconductor material from which it is made, but then trapped within it. The more photons that are received, the more electrons get released and trapped, so charging it up. The charges on each pixel can be 'read' to give a measure of the intensity of the incident light and set up to do this on a pretty much continuous basis.

Your task

To investigate the effect on the detection of a model exoplanet of one or more of the following:

- the diameter of the model exoplanet
- the brightness of the model star
- the colour of the model star
- rate of sampling
- speed of motion of the model exoplanet

Measuring the light intensity

In place of a CCD array you will be using the Vernier Light Sensor which incorporates a Hamamatsu S1133 silicon photodiode to measure the illumination or light intensity. It has been arranged in what is known as a reverse-bias with a resistor so that the tiny current flowing through them is directly proportional to the Illumination/light intensity. Like all microprocessor-based devices, the *LabQuest* datalogger will only accept sensor inputs as voltages. So if electric currents are to be measured they must first be converted to voltages. The resulting voltage across the resistor is then amplified and fed into an analogue to digital (A to D) converter. The A to D converter is the electronic device which converts these analogue voltages into digital ones. The different ranges available on the Light Sensor are the result of differing degrees of amplification.

Setting up your investigation

If mains power is available for the *LabQuest*, plug in its power adapter.

You will have been provided with two lengths of black square-section pipe. The longest section represents deep space between the exoplanet and the detector in Earth orbit. The shorter section represents the space between the star and the exoplanet. Leave a space of a centimetre or so between the two sections so that the model exoplanets can make a transit across the gap.

Thread a 1cm diameter model exoplanet onto the thin wire holder.

If it has not already been done, carefully fit the Vernier Light Sensor into the expanded polystyrene end cap and then into the 'Photometer' marked end of the long section of pipe. Similarly plug the Light Sensor into Channel 1 on the rear of *LabQuest*. Set the switch on the Range Box to 0-600 lux.

Again if it has not already been done, fit a red coloured bulb into the Light Bulb Holder and position it up against the short length of the pipe marked 'Star' so that the bulb faces down the pipe towards the Light Sensor. Connect the Light Bulb Holder's sockets to a low voltage variable d.c. supply and connect a d.c. multimeter on its 20V range in parallel with the light bulb. Do **not** switch this low voltage d.c. supply on yet.

It should now be set up as shown in Figure 7.

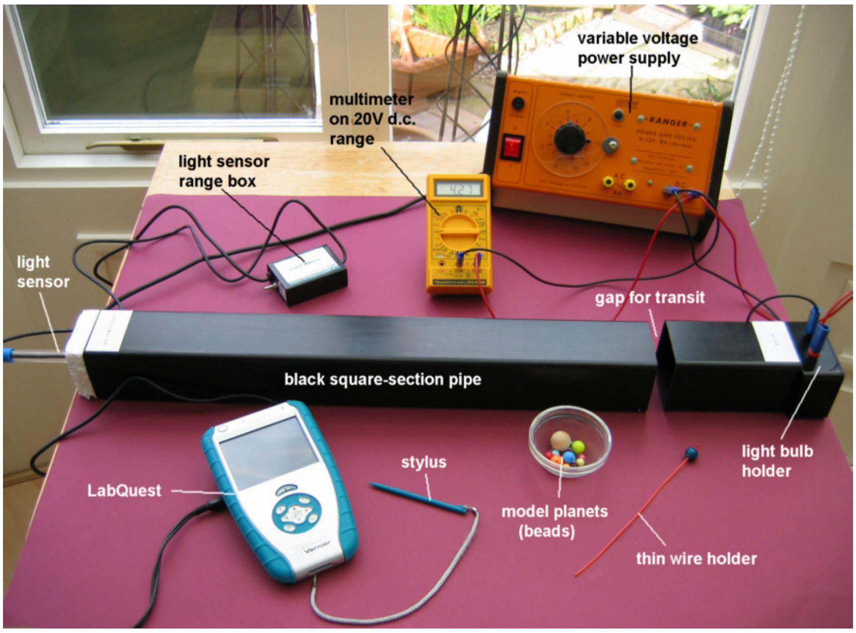

Figure 7 Set up of Light Sensor and Light Bulb Holder at opposite end of the black pipe

Now switch *LabQuest* **ON** by pressing the silver **ON**/**OFF** button in its top left-hand corner. You should then see displayed a screen similar to that of Figure 8 on the following page.

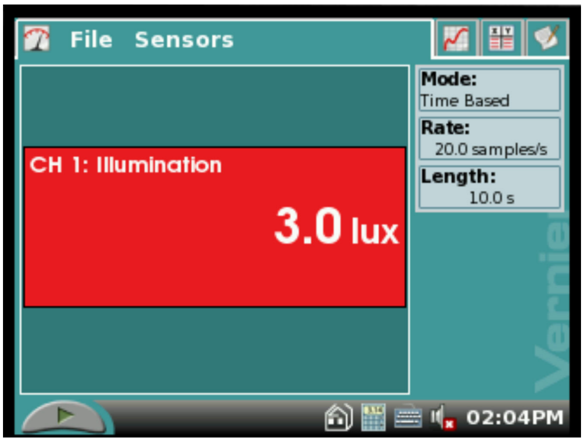

Figure 8 Opening screen

Switch **ON** the variable voltage d.c. power supply and raise its output voltage to 4.5V.

Tap the stylus on the **Rate** box to display the initial Data Collection screen much like that shown in Figure 9.

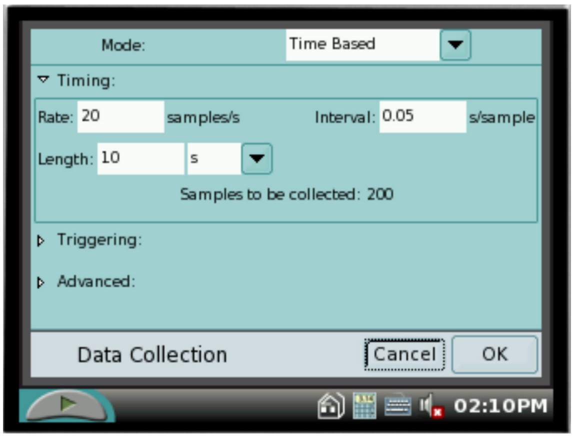

Figure 9 Initial Data Collection screen

Keep in Time Based mode but change the Rate to 100 samples/s which automatically indicates an Interval of 0.01 s/sample. Use the stylus with the on-screen keyboard to do this. Set the Length (time over which data will be collected) to 10s if it is not already so. Now tap the **OK** button.

Tap the **Graph** tab  to display the initial empty graph screen like that shown over the page in Figure 10.

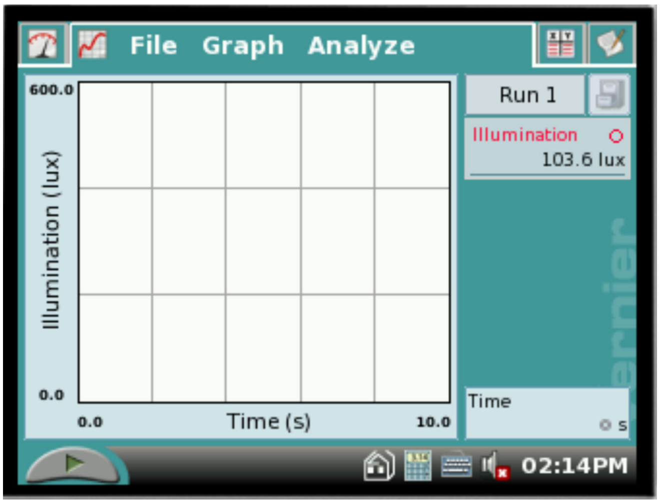

Figure 10 Initial empty graph screen

Tap **Graph** and then **Graph Options** in the associated drop-down menu to reveal the Graph Options screen displayed in Figure 11.

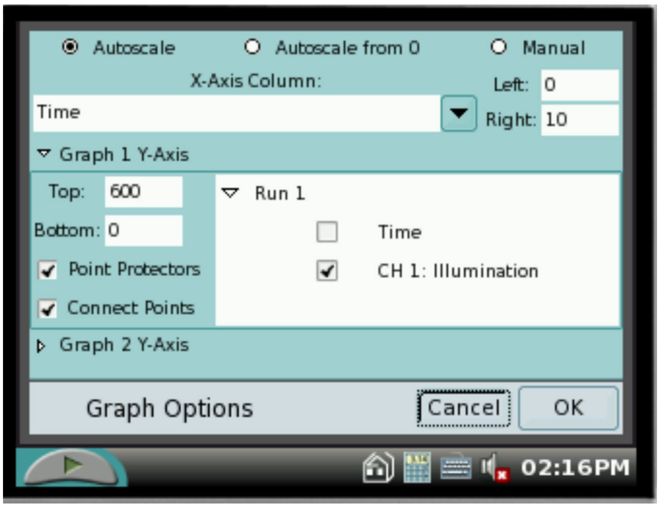

Figure 11 Initial Graph Options screen

Often one makes use of the Autoscale option but here you need to set the scales manually by tapping the stylus on the **Manual** radio button. Then, if not already set, use the stylus and on-board keyboard to set the Time X-axis Column Left to '0' and Right to '10', the Graph 1 Y-axis Top to '600' and Bottom to '0'. Ensure that the box alongside CH 1:Illumination is ticked but leave the box alongside Time unticked. Tap in the box alongside Point Protectors to untick it, but ensure that the box alongside Connect Points is ticked. It should now display as in Figure 12 on the next page.

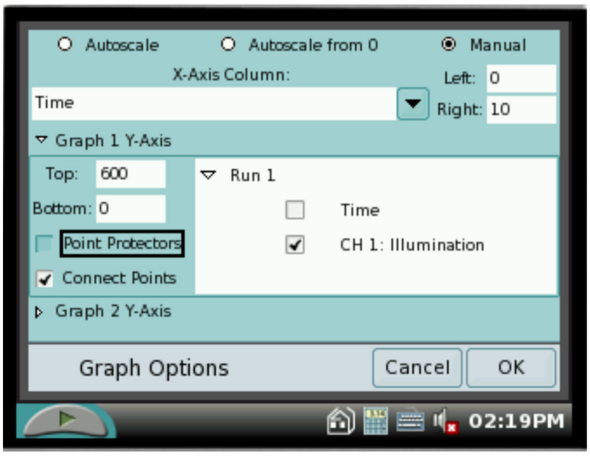

Figure 12 Graph Options setup

Tap the **OK** button.

You are now ready to conduct the first experiment. Tap the **Start/Stop collecting data** button  and move the model exoplanet slowly through the gap between the two pieces of downpipe, wait for just a moment and then move it quickly back through the gap. You have just 10 seconds for the there and back movement. You should see the graph display something similar to that shown in Figure 13.

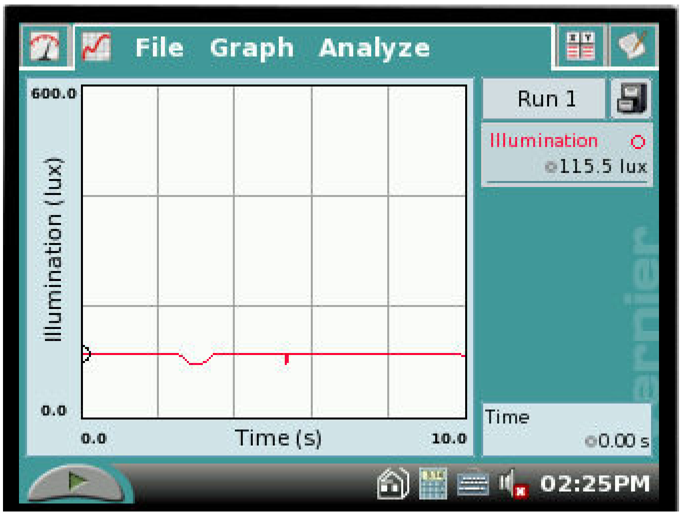

Figure 13 Typical graph display of Light Curve of transit

You have now modelled a transit of the star to obtain the 'Light Curve'.

Q1 How easily was the model exoplanet detected when (i) moving slowly and (ii) moving quickly?

Replace the 1cm bead on the wire by a smaller 0.5cm one to represent a smaller exoplanet.

Tap the **Start/Stop collecting data** button and repeat the movement of the model exoplanet through the gap between the pieces of downpipe.

Q2 What, if any, difference did you notice in the ability to detect this smaller model exoplanet?

Raise the voltage output from the variable voltage d.c. supply to 7.0V.

Q3 What effect does this rise in voltage have on the brightness of the model Sun?

Replace the bead on the wire by the 1cm diameter one. Tap the **Start/Stop collecting data** button and repeat the movement of the model exoplanet through the gap between the pieces of downpipe. Repeat with the smaller bead.

Q4 What, if any, difference did you notice in the ability to detect the model exoplanets?

Tap on the **Meter tab** to display a screen similar to that of the opening screen in Figure 8. Tap on the Rate box and use the stylus and on-board keyboard to change the Rate to just 1 sample/s. Tap **OK**.

Lower the voltage output of the variable voltage d.c. supply to 4.5V.

Replace the bead on the wire by the 1cm diameter one. Tap the **Start/Stop collecting data** button and repeat the movement of the model exoplanet through the gap between the pieces of downpipe. Repeat with the smaller bead.

Q5 What, if any, difference did you notice in the ability to detect the model exoplanets?

Raise the voltage output from the variable voltage d.c. supply to 7.0V.

Replace the bead on the wire by the 1cm diameter one. Tap the **Start/Stop collecting data** button and repeat the movement of the model exoplanet through the gap between the pieces of downpipe. Repeat with the smaller bead.

Q6 What, if any, difference did you notice in the ability to detect the model exoplanets?

Switch **OFF** the light bulb for a minute or so to let it cool. Replace it with the blue bulb. Switch **ON** the power supply and adjust the voltage across the bulb to 4.5V.

Tap on the **Meter tab** to display a screen similar to that of the opening screen in Figure 8 again. Tap on the Rate box and use the stylus and on-board keyboard to change the Rate back to 100 sample/s. Tap **OK**.

Replace the bead on the wire by the 1cm diameter one. Tap the **Start/Stop collecting data** button  and repeat the movement of the model exoplanet through the gap between the pieces of downpipe. Repeat with the smaller bead.

Raise the voltage output from the variable voltage d.c. supply to 7.0V.

Replace the bead on the wire by the 1cm diameter one. Tap the **Start/Stop collecting data** button  and repeat the movement of the model exoplanet through the gap between the pieces of downpipe. Repeat with the smaller bead.

Now switch **OFF** the variable voltage d.c. supply.

Q7 What, if any, difference did you notice in the ability to detect the model exoplanets with this model star emitting blue light instead of red and suggest why this might be the case?

The light curve for the exoplanet transit of TRES-1 (Trans-Atlantic Exoplanet Survey), an 11.8 magnitude star about 500 light-years away in the constellation of Lyra is shown in Figure 15 on the following page. It was produced by Professor Tom Michalik and senior physics major Tracey Wellington of Randolph College in USA over a period of just over four hours on the night of 19/20 September 2004. This exoplanet is Jupiter-like and orbits the star once every 3.03 days.

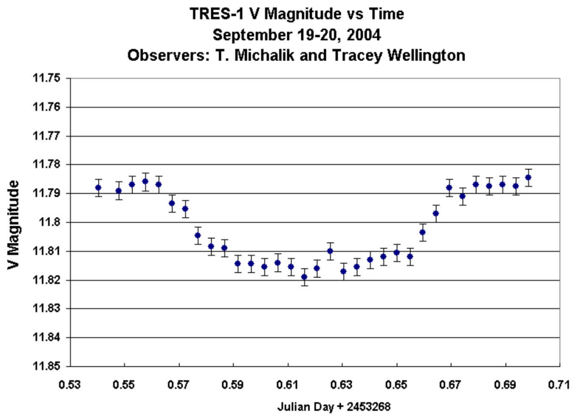

Figure 15 Light curve of exoplanet transit of TRES-1
(Courtesy Prof Tom Michalik and Tracey Wellington)

Hopefully you can see the similarity between the light curve of the real exoplanet's transit across a star and your modelled transits.

Deleting datasets and finishing

To leave things set up for other users tap **File** and **Quit** and then **Discard** in response to 'You have unsaved data. Do you wish to save or discard the data?'.

Carefully unplug the light sensor from *LabQuest* and then press the silver **ON/OFF** button to switch *LabQuest* **OFF.**