

## Activity 34 -Transit of Venus - the Astronomical Unit

**Year Level** : Years 10 to 12 (typically 15 to 18 years of age).

**Background** : This exercise illustrates the phenomenon of transits. A *transit* of a planet occurs when a planet (Mercury or Venus) passes directly between the Earth and the sun, so that we see the dark silhouette of the planet move across the face of the sun. While transits of Mercury are relatively common, occurring once or twice every decade, transits of Venus are extremely rare, occurring no more than twice a century. The first transit of Venus ever observed occurred in 1639, and since then, only 6 transits of Venus have occurred, the latest being on June 6, 2012, and the next one not until 2117.

Despite being so rare, transits of Venus have played an important role in the history of astronomy. For the Venus transits of 1761, 1769, 1874, and 1882, many governments organized elaborate and expensive expeditions to remote parts of the globe so that astronomers could view the transit from several different sites. The reason for such interest is that transits of Venus provided a unique opportunity to determine the length of the **Astronomical Unit**, which is the average distance between the Earth and the sun, a fundamental scale in the universe.

**Aim** : To determine the value of the Astronomical Unit using the simulation program TRANSITS OF VENUS AND MERCURY available from the Contemporary Laboratory Experiences in Astronomy (CLEA) website and to gain an appreciation of the historical role of science as a Human Endeavour.

**Shape of the Australian Curriculum: Science strands on focus areas.**

**Content descriptors: Year 11 and 12 (as per Year 10)**

Science Understanding	Science as a Human Endeavour	Science Inquiry Skills
<p>Yr 10</p> <p>The universe contains features including galaxies, stars and solar systems and the Big Bang theory can be used to explain the origin the universe (ACSSU188)</p>	<p>Yr 10</p> <p>Scientific understanding, including models and theories, are contestable and are refined over time through a process of review by the scientific community (ACSHE191)</p> <p>Advances in scientific understanding often rely on developments in technology and technological advances are often linked to scientific discoveries (ACSHE192)</p>	<p>Yr 10</p> <p>Plan, select and use appropriate investigation methods, including field work and laboratory experimentation, to collect reliable data; assess risk and address ethical issues associated with these methods (ACSIS199)</p> <p>Select and use appropriate equipment, including digital technologies, to systematically and accurately collect and record data (ACSIS200)</p>

	<p>People can use scientific knowledge to evaluate whether they should accept claims, explanations or predictions (ACSHE194)</p>	<p>Use knowledge of scientific concepts to draw conclusions that are consistent with evidence (ACSIS204)</p> <p>Communicate scientific ideas and information for a particular purpose, including constructing evidence-based arguments and using appropriate scientific language, conventions and representations (ACSIS208)</p>
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**Please note: For this exercise you will have to download ‘THE TRANSIT OF VENUS AND MERCURY’ from the following website.**

**<http://www3.gettysburg.edu/~marschal/clea/CLEAhome.html>**

**This lesson plan is a summary of the student manual that is supplied for this tutorial. All the information in this lesson has been extracted from the student manual, however, specific learning objectives and other information about transits can be found in the manual.**

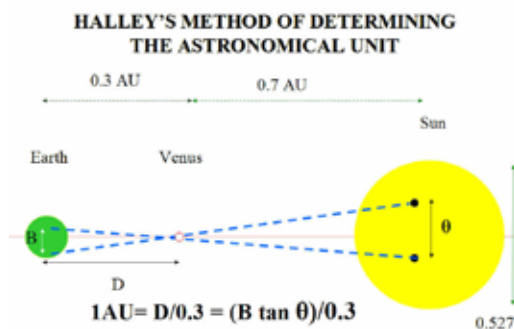
## BACKGROUND HISTORY

With the establishment of the sun-centered Copernican planetary system in the 1600's, astronomers were faced with the question of the size of the solar system. Using observations of Tycho Brahe, Johannes Kepler was able to determine the relative sizes of the orbits of the planets in terms of the distance from the Earth to the sun, the Astronomical Unit. These values are shown in the table below.

<b>RELATIVE SIZE OF PLANETARY ORBITS</b>	
<i>Planet</i>	<i>Semi major Axis of Orbit (AU)</i>
Mercury	0.39
Venus	0.72
Earth	1.00
Mars	1.52
Jupiter	5.20
Saturn	9.54

Even though Kepler had calculated the *relative* scale of the solar system quite accurately, astronomers in those days did not have an accurate measure of the *absolute* size of the solar system, in other words the true number of miles in an Astronomical Unit.

In 1715, Edmund Halley (of Halley's comet fame), first proposed a workable method of determining the Astronomical Unit using observations of transits of Venus. Halley's method involved a time-honoured way to measure distances using simple trigonometry. If two observers at different locations on the Earth could simultaneously view Venus as it passed in front of the sun, a northern observer would see the planet shifted to the south on the face of the sun with respect to what a southern observer would see. This shift, called *parallax*, depends on the distance between the two observers on the earth. If the parallax,  $\theta$ , is measured, and the *baseline* or distance B, that is the distance between the two observers, is known, then a simple trigonometric formula gives the distance between the earth and Venus, as shown in Figure 1 below.



Once the distance to Venus is known, the length of the Astronomical Unit can be found, since the distances between the sun and Venus and between the earth and Venus in Astronomical Units are known.

Though Halley died in 1742 without ever seeing a transit, his method appeared so promising that astronomers began to prepare to observe the track of Venus across the sun at transits in 1761 and 1769.

Britain and France sent major expeditions to observe the transits of 1761 and the transit of 1769. **Captain James Cook's** famous first voyage to the South Pacific was undertaken to observe the 1769 transit of Venus from Tahiti. Although many of the observers had good weather during the transit, and though many measurements were taken, the results of these elaborate observations were somewhat disappointing. The best calculations from the observations in the 1700's put it between 92 and 95 million miles.

There were two transits again in the 19<sup>th</sup> century, in 1874 and 1882, and even more elaborate preparations were made to observe the track of Venus across the sun. The United States, Britain, France, Italy, Russia, Holland, and Denmark all mounted expeditions. Technology had advanced by this time, and astronomers used photographs to record the position of Venus more precisely than they had been able to do a century earlier. But again, the results were not as good as hoped; as precise timing of the duration of the transit just was too hard to attain.

There were no transits of Venus in the 20<sup>th</sup> century, but by the time of the next transit, on June 8, 2004, Halley's transit method had been superseded by several better and more precise methods of measuring the length of the Astronomical Unit, and the size of the solar system was known within a fraction of a percent error. Nevertheless transits remain of great interest, both as rare and beautiful manifestations of the movements of objects in the solar system and as opportunities to apply modern technology to classic methods of astronomy—let us do just that in the exercise that follows.

### **Pre reading information**

In order to assist with the understanding of this tutorial it is important that the meaning of the following terms is known.

Angle	Astronomical Unit	Baseline	Cartesian Coordinates	Celestial Coordinates
Declination	Degree, Minutes, Seconds	Inferior Planet	Latitude	Longitude
Orbit	Parallax	Superior Planet	Radian	Right Ascension
Solar Diameter	Solar Radius	Terrestrial Coordinates	Transit	Universal Time

Complete the following crossword (using the words above) in order to help with your understanding of the above terms and use the internet, a textbook or dictionary if you are unsure of the correct response. Two words allow for a gap between them.

#### **Across**

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3. About 110 times the diameter of the Earth.
10. One of the two coordinates of the equatorial coordinate system, which in astronomy is comparable to geographic latitude, but projected onto the celestial sphere. It is measured in degrees north and south of the celestial equator.
13. The path of a celestial body or an artificial satellite as it revolves around another body.
14. An apparent change in the position of an object resulting from a change in position of the observer.
15. The coordinate system that we use to locate places on Earth.
17. A unit of angular measurement equal to one sixtieth (1/60) of one degree.
19. A unit of angle measurement.
20. The \_\_\_\_\_ of a location on the Earth is the angular distance of that location north or south of the equator. It is an angle, and is usually measured in degrees.
21. Any of the five planets (Mars, Jupiter, Saturn, Uranus, and Neptune,) whose orbit lies outside that of the Earth.

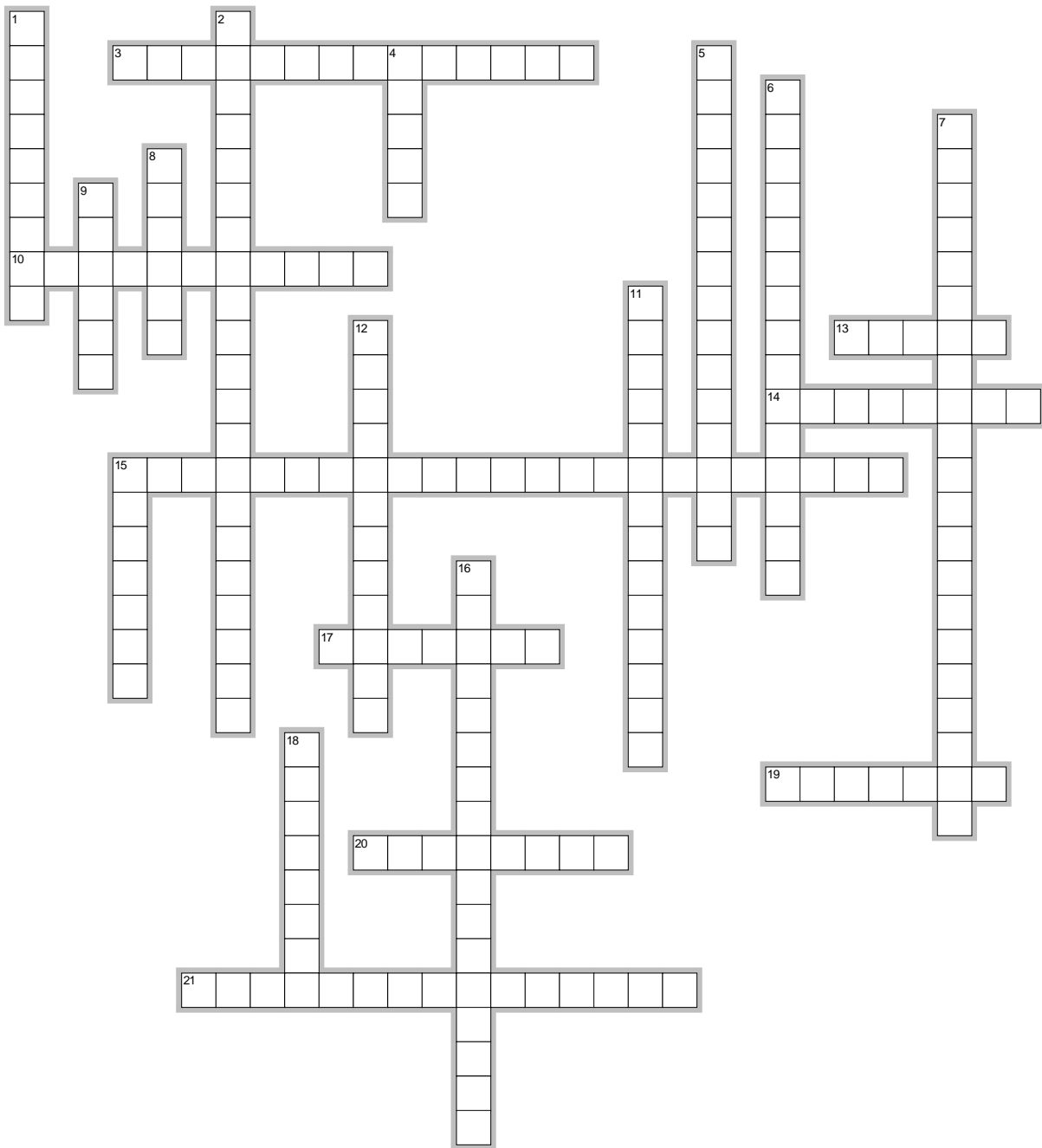
#### **Down**

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1. A geographic coordinate that specifies the east-west position of a point on the Earth's surface. It is an angular measurement, usually expressed in degrees, minutes and seconds.
2. A coordinate system in which locations of points in space are expressed by reference to three mutually perpendicular planes, called coordinate planes.
4. The figure formed by two rays sharing a common endpoint, called the vertex of the angle.
5. The angular distance measured eastwards along the celestial equator from the vernal equinox to the point at which the celestial equator intersects a great circle

- passing through the celestial pole and the heavenly object in question.
6. A term used in reference to Mercury and Venus, which are closer to the Sun than the Earth.
  7. A coordinate system for mapping positions on the celestial sphere.
  8. A unit of angular measure equal to the angle subtended at the centre of a circle by an arc equal in length to the radius of the circle, approximately  $57^\circ$ .
  9. A unit of angular measurement equal to one sixtieth ( $1/60$ ) of one minute.
  11. A time scale based on the rotation of the Earth.
  12. About 110 times the radius of the Earth.
  15. The astronomical event that occurs when one celestial body appears to move across the face of another celestial body, hiding a small part of it, as seen by an observer at some particular vantage point.
  16. Approximately the mean distance between the Earth and the Sun.
  18. A measurement, calculation, or location used as a basis for comparison.

### **TRANSIT OF VENUS TERMINOLOGY**



EclipseCrossword.com

## Solution

### Across

- 3. SOLAR DIAMETER**—about 110 times the diameter of the Earth.
- 10. DECLINATION**—is one of the two coordinates of the equatorial coordinate system, In astronomy is comparable to geographic latitude, but projected onto the celestial sphere. It is measured in degrees north and south of the celestial equator.
- 13. ORBIT**—The path of a celestial body or an artificial satellite as it revolves

around another body.

14. **PARALLAX**—an apparent change in the position of an object resulting from a change in position of the observer.
15. **TERRESTRIAL COORDINATES**—the coordinate system that we use to locate places on Earth.
17. **MINUTES**—is a unit of angular measurement equal to one sixtieth (1/60) of one degree.
19. **DEGREES**—a unit of angle measurement.
20. **LATITUDE**—the \_\_\_\_\_ of a location on the Earth is the angular distance of that location north or south of the equator. It is an angle, and is usually measured in degrees
21. **SUPERIOR PLANET**—any of the five planets (Mars, Jupiter, Saturn, Uranus, and Neptune,) whose orbit lies outside that of the earth.

## Down

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1. **LONGITUDE**—is a geographic coordinate that specifies the east-west position of a point on the Earth's surface. It is an angular measurement, usually expressed in degrees, minutes and seconds.
2. **CARTESIAN COORDINATES**—a coordinate system in which locations of points in space are expressed by reference to three mutually perpendicular planes, called coordinate planes.
4. **ANGLE**—is the figure formed by two rays sharing a common endpoint, called the vertex of the angle.
5. **RIGHT ASCENSION**—the angular distance measured eastwards along the celestial equator from the vernal equinox to the point at which the celestial equator intersects a great circle passing through the celestial pole and the heavenly object in question.
6. **INFERIOR PLANET**—a term used in reference to Mercury and Venus, which are closer to the Sun than the Earth.
7. **CELESTIAL COORDINATES**—a coordinate system for mapping positions on the celestial sphere.
8. **RADIAN**—A unit of angular measure equal to the angle subtended at the center of a circle by an arc equal in length to the radius of the circle, approximately 57°.
9. **SECOND**—is a unit of angular measurement equal to one sixtieth (1/60) of one minute.
11. **UNIVERSAL TIME**—is a time scale based on the rotation of the Earth.
12. **SOLAR RADIUS**—about 110 times the radius of the Earth.
15. **TRANSIT**—is the astronomical event that occurs when one celestial body appears to move across the face of another celestial body, hiding a small part of it, as seen by an observer at some particular vantage point.
16. **ASTRONOMICAL UNIT**—is approximately the mean distance between the Earth and the Sun.
18. **BASELINE**—a measurement, calculation, or location used as a basis for comparison.

The data for the CLEA Transit of Venus exercise consists of three series of images taken with these GONG (**Global Oscillation Network Group**) solar telescopes on June 8, 2004:

- 54 images from El Teide between **7:05** and **11:35** Universal Time
- 39 images from Udaipur between **5:15** and **10:50** Universal Time
- 36 images from Learmonth between **5:00** and **8:50** Universal Time



Two sample images from this set are shown in Figure 2 below.

A note about the images: they are 860 x 860 pixels in size, and oriented so that north is up and west is to the right, the same as we would see the sun in the sky in the Northern Hemisphere. **The solar disk is about 720 pixels across on each image and each pixel corresponds to 2.5 arc seconds.** Venus moves across the sun from east to west (left to right) during the transit. The shift we expect to see in the position of the silhouette of Venus between the various observing sites is only a few pixels, but it is easily measured on these digital images using the software provided in this exercise.

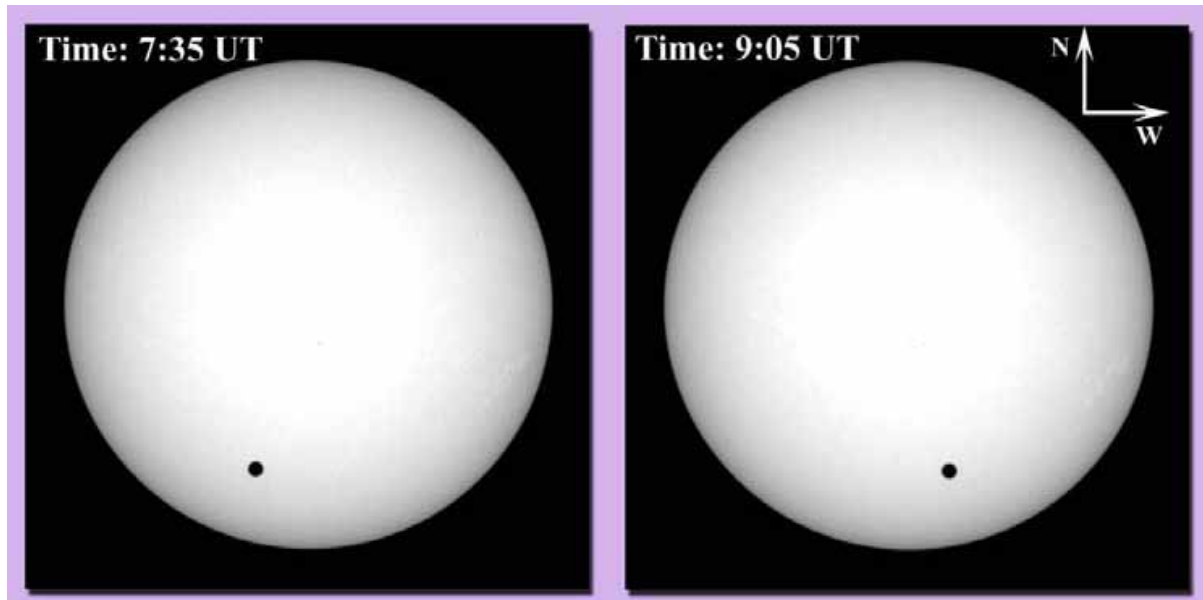


Figure 2: Two typical images of the Sun from GONG showing both the sun and the silhouettes of Venus as it transited from east to west across the sun on June 8, 2004 . Arrows have been added to indicate directions on the sky.

### **Basic Strategy: Using the GONG Images of the Transit.**

Your primary task is to compare the tracks of Venus across the sun as seen from a pair of GONG telescopes at two different observing sites and determine the angular shift or *parallax*,  $\pi_m$ , in seconds of arc, between the two tracks *at one particular time*.

From the value of that angular shift, and the known distance between the two sites, you can then determine the distance between the earth and Venus. The basic data are the images from the GONG telescopes. From them, you plot two tracks, and from the plot you measure the angular shift. A sketch of the two tracks and the angular distance you will be measuring is shown in Figure 3.

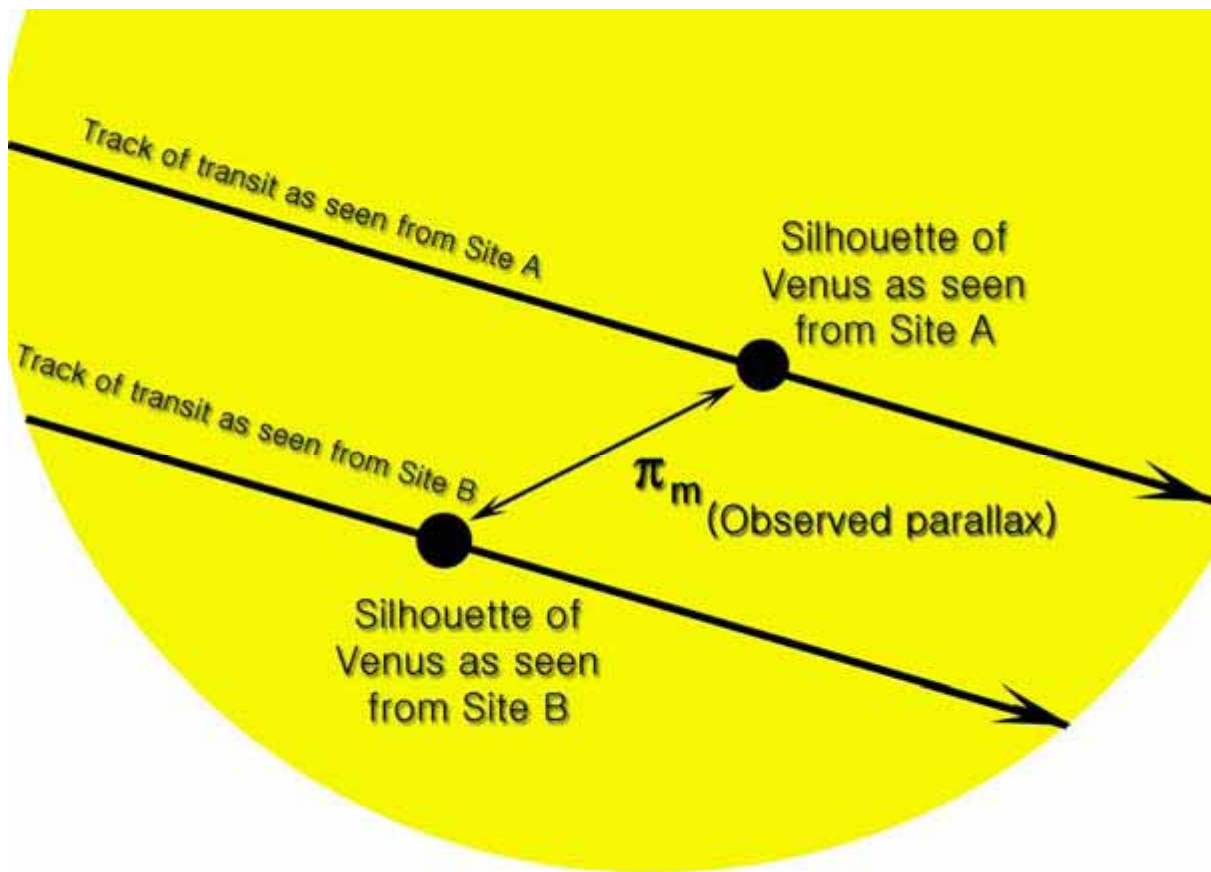


Figure 3: The tracks of Venus across the sun as seen from two sites. Also shown are the appearance of the silhouette of Venus from the two sites as seen at the same time, and the observed parallax of Venus,  $\pi_m$ .

**Here are some questions you should ask yourself, and which you should try to answer when looking at the images:**

- If one observing site is further north on the Earth than the other, which transit track should appear the farthest north on the sun? Why?
- Which transit track should appear the farthest south on the sun?
- The observing sites also differ in that they are spread out east to west on the earth. If observations of the silhouette of Venus are made at exactly the same time (UT) from all three sites, which site will see Venus further to the east on the sun? Which site will see Venus further to the west?
- Since there are three sites, how many parallax shifts could you measure from the data? Is it better to use just one, or to measure all of them and take an average?

### **CALCULATING THE ASTRONOMICAL UNIT FROM THE MEASURED PARALLAX OF VENUS**

You have measured a parallax  $\pi_m$  from your observations of the transit from any two sites. **(Be sure to express this in arc seconds. If your value of the parallax is in fractions of the radius of the sun, be sure to multiply it by the number of arc seconds in the radius of the sun. The solar disk is about 720 pixels across on each image and each pixel corresponds to 2.5 arc seconds.)**

In addition to the measurement of  $\pi_m$ , there are a few quantities that you need to know in order to calculate the length of the Astronomical Unit. The CLEA software will help provide them for you:

- The baseline, **B** between the two sites in kilometres, measured in a direction perpendicular to the line of sight between the centre of the earth and the sun. The CLEA software includes a simple program that calculates this, given the Universal time of the observation, the celestial coordinates (right ascension and declination) of the sun, and the terrestrial coordinates (latitude and longitude) of the two observing sites.
- The distance between the earth and Venus,  $D_{ev}$  and the distance between the earth and the Sun (in astronomical units),  $D_{es}$  at the time of the eclipse, **expressed in Astronomical Units** (you don't yet know what the absolute value of the Astronomical Unit is, but you do know the **relative distances in the solar system in AU.**)

The simple formula you use to calculate the length of the Astronomical Unit **A** in km is:

$$A = \frac{B \cdot (D_{es} - D_{ev}) \cdot 206265}{\pi_m \cdot D_{ev} \cdot D_{es}}$$

**CAUTION:** Be sure your units are correct before you plug into this formula. B is in km,  $D_{ev}$  and  $D_{es}$  are both in AU, and  $\pi_m$  is in arc seconds!

**Here is a summary of what you will be doing:**

**OBSERVATIONAL DATA (what you measure or are given):**

- The parallax of the silhouette of Venus as seen at a particular time from two sites, determined from plotting the positions of Venus on two series of GONG images
- The baseline between the two sites, determined by knowing the latitude and longitude of the sites and the particular time of the observation (which determines the direction to the sun.)
- The distance between the earth and Venus and the earth and the sun in Astronomical Units at the particular time of the observation, which is known from KEPPLER'S laws.

**WHAT YOU CALCULATE FROM THIS:**

- **The length of the Astronomical Unit in Kilometres.**

# A USER'S GUIDE TO TRANSITS OF VENUS AND MERCURY

## A Program for Displaying and Measuring Transits across the Sun



**Position the mouse over the icon Transit lab** or **menu bar** and **click** to start the program. When the program starts, the CLEA logo should appear in a window on your screen. Go to the **File menu** at the top of that window, **click on it**, and select **the login option** from the menu. **Fill in** the form that appears with your name and laboratory table number. When all the information has been entered to your satisfaction, **click OK** to continue, and **click “yes”** when asked if you are finished logging in. The opening screen of the *Transits of Venus and Mercury* lab will then appear.

**Click on** the file menu and **choose Run. Click on 2004 Venus Transit.**

When you first run the program you will see a Main File List area with two frames, the left labelled **Loaded Image List** and the right labelled **Image Database Directory**. Both will be blank. **Click on the File menu** and then **Image Database, Image Directory and Load**. You can load a database of images taken during the transit from one of the three observing sites (**double click** with the left mouse button on **Teide, Canary Islands**). After you load the image database from the *File* menu, you will see a list of the available GONG images, ordered by Universal Time of the image, in the Image Database Directory.

**Right-click** on the Image Database Directory box which will give you a set of selection and display choices. **Click on Select all** and then **right click** on the **Image Database Directory** again and select **Load Selected Images**. It may take a minute or so for them all to load, and while they are loading you will see them appear one by one in a display window on your screen while a window displays the progress of the load (the percentage of files loaded). When all files have loaded, **click the OK** button on the window which has been listing the progress of the load. You will notice an image of the Sun appear and this is the final image in your Loaded Image List. You can display any of the images in the Loaded Image List window by double clicking on the image time. (You can also use the right mouse button to bring up a pop-up menu that will allow you to display the image, remove it, or remove all the images currently loaded) .

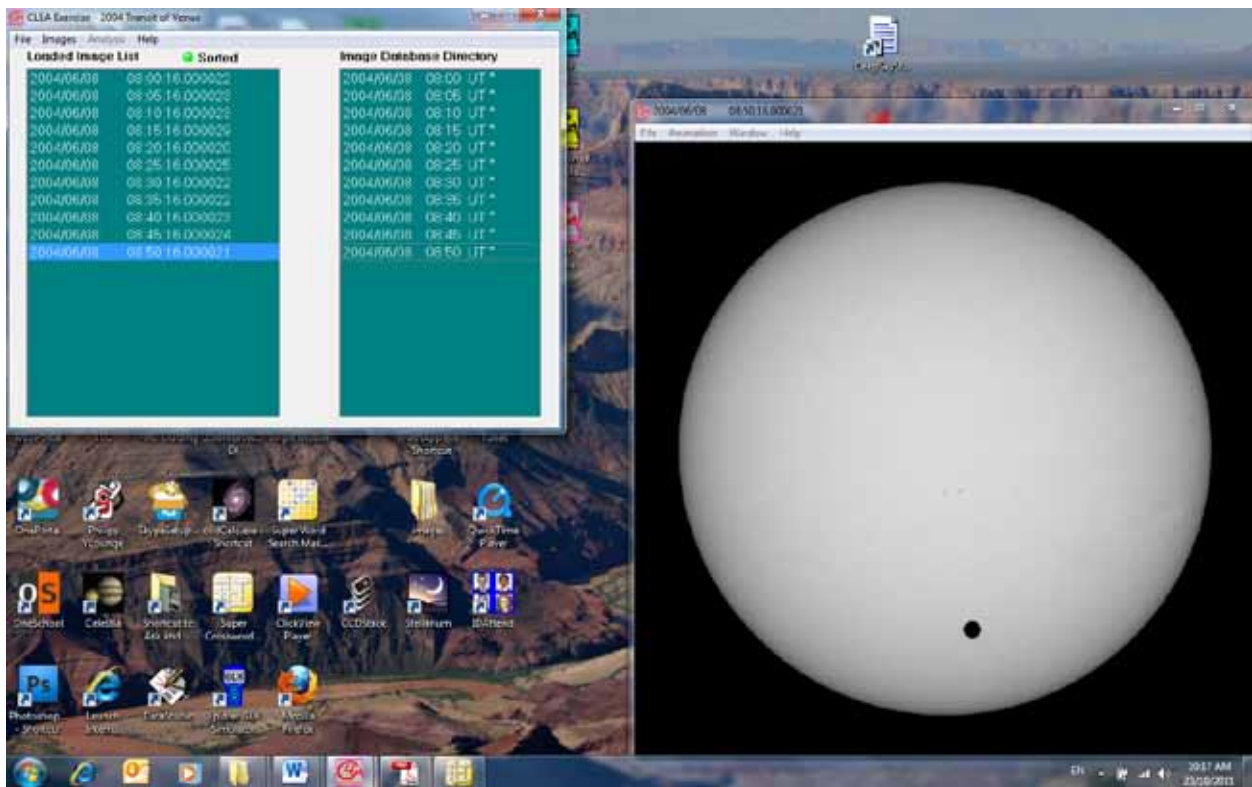


Figure 4: Main window and image display window.

### Animating a Series of images

Once you have a series of images loaded, you can have the program display each one in sequence automatically as an animation. This is a nice way to watch the entire transit in “fast motion”. You can do this in either of two ways. On the main menu bar over the list of images, **select the *Images* option**, then **select *Animation***. Or on the menu bar over the ***Image Display window***, **select *Animation---On***. The rate of the animation (how long it displays each image) can also be set from this menu bar. You can stop the animation using the same menu bars.

### Measuring the Positions of the Silhouette of the Transiting Planet

The most notable feature on all the images is the silhouette of Venus. In order to plot the track of the planet across the sun you need to measure the position of this silhouette on every image of the series. It’s a bit tedious, but the software makes it very easy.

The image display permits you to measure the positions of points on the image, and it will automatically measure the coordinates of the centre of the silhouette. To start measuring silhouette positions, **begin at the top of the Loaded Image List**, and by **left clicking** on each image date one by one, find the first one on which the entire silhouette appears furthest to the left. (The first few may not show the silhouette, or may only show part of it).

To measure you need **only left click on the displayed image**, or you can choose **File---Image---Measure** from the menu bar at the top of the image display. A small window will appear with digits to indicate the position of the cursor in *pixels* and in *solar radii* (fractions of the apparent radius of the sun). The position of the cursor is updated whenever you click the left mouse button, or continuously if you hold the button down. You will also see a small magnification window that shows the area

around the cursor. (see figure 5). This will allow you to locate the centre of Venus in the crosshairs.

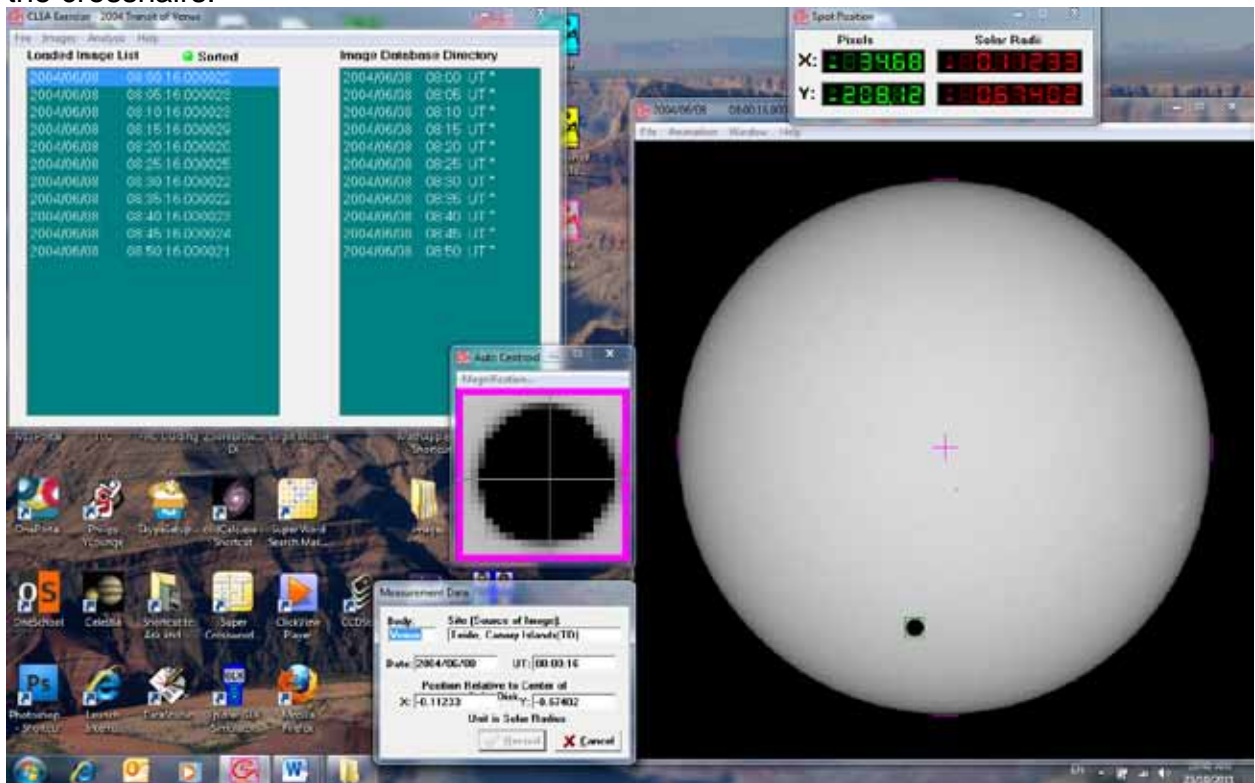


Figure 5: Measuring the positions of silhouettes on the images.

## Recording Data

Once you have located the centre of Venus for the first image you will want to record the data. When you are measuring silhouette positions, there will be a small window on the screen (usually at the lower left) labelled *Measurement Data*. When you click the “record” button, the image date and time and the position of the cursor are written to a data file. If your instructor has turned on the “automatic centroiding” feature, which is usually the case, the software will calculate the precise **centre** of the silhouette beneath the cursor when you click the right mouse button. ( If the automatic centroiding feature is not turned on, place the cursor as close to the centre of the spot as possible before recording the position. ) The small magnification window helps by giving a magnified view of where the cursor is pointing, and the amount of magnification can be set, if desired, using a menu on the magnification window. The computer remembers whether you’ve measured a particular image, and will not let you measure it twice. (See the next section to find out how to delete erroneous data).

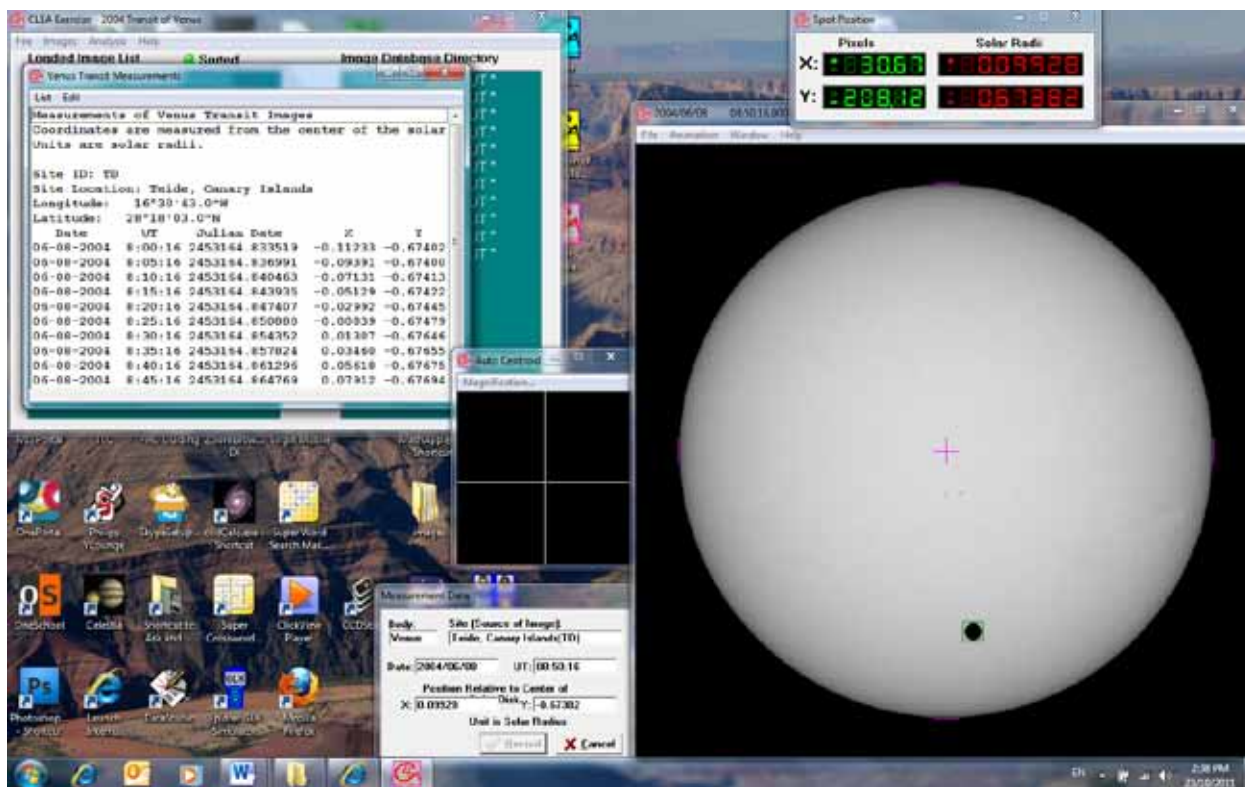


Figure 6 : Recorded data listings.

## Saving Data

When you have completed measuring all the positions from **Teide, Canary Islands** save the data; you may, in fact want to save the data even before you have finished from the site just to guard against loss. Simply use the **File—Measurement Data—Save Data** menu on the main window and give the file a name. Then if you make a mistake or the computer system crashes, you can retrieve the data without having to remeasure it.

## Seeing Tables and Plots of Recorded Data

At any time after you have some data recorded, you can view all the recorded data in a separate *Transit Measurements* window. To do this, go back to the *Main File List* window and choose **File---Measurement Data** from the main menu bar. There are choices that let you view the current data, or load a file of previously saved data. If you choose to view the list, you will see the data window appear on the screen. (see Figure 6 above). The columns are labelled; the observing site is at the top, and the x and y position of the centre of the planet on each image is given in units of fractions of a solar radius. In addition to the date and time of the observation, the window will list the *Julian Date* of the observation, which is a running day number and fraction that is convenient for keeping track of astronomical times.

You can print the data in the *Transit Measurements* window by choosing **List---Print** from the menu bar. You cannot edit individual measurements, since they were made automatically when you clicked on the image on a picture; but if an entry seems to be in error, you can delete it by selecting the line (with a left click of the mouse), and using the **Edit** menu on the menu bar to select **Delete Selected Line**.

It is also possible to view the measurements you are making in graphical form, against a circular image of the sun. Simply click on the **Analysis** item menu bar on

the main window and **select Plot/Fit Data**. A window will open showing a plot of your position measurements as small circles, connected by straight lines to represent the track of the planet across the face of the sun. The **View** choice on the menu bar of this window will allow you to see the track on the scale of the whole sun, or a magnified view (**Detail**). The magnified view is especially useful when comparing the tracks as seen from two or three sites, because the difference between the tracks is small and can best be seen when magnified.

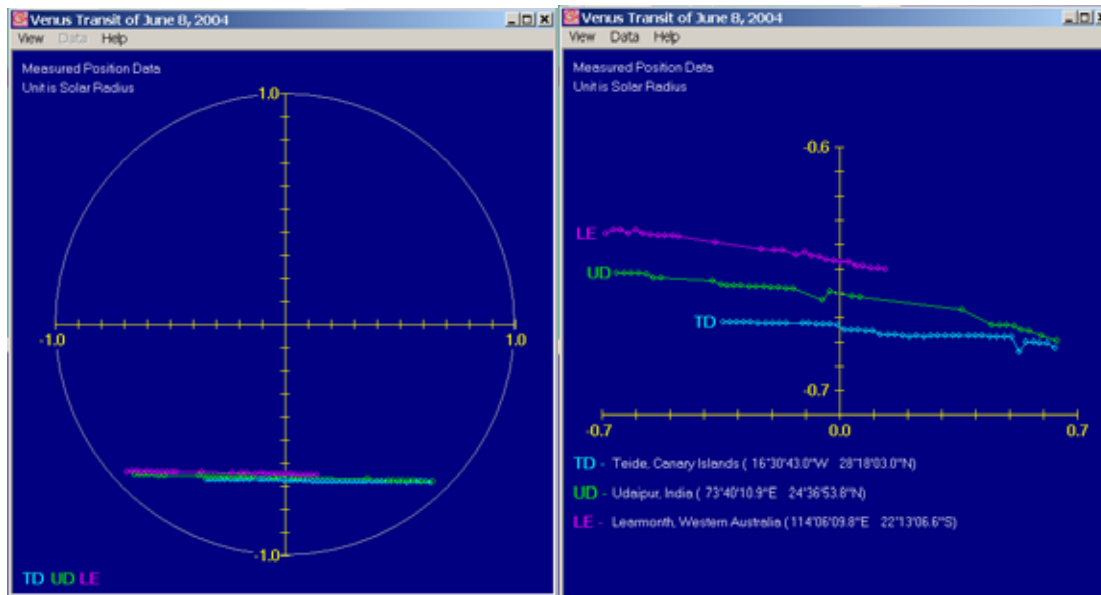


Figure 7: Graphical plots of measurements show the track of the planet across the sun.

On the left is a full disk view; on the right, the magnified view.

### Measuring tracks from a second site

You will want to measure the transit tracks from Learmonth, Western Australia. To view the images from another site, just go back to the main window, **File --- Image Database---Image Directory---Load** choice and double click on the listing for Western Australia. Select all the images from this site. **Right-click** on the Image Database Directory box which will give you a set of selection and display choices. **Click on Select all** and then **right click** on the **Image Database Directory** again and select **Load Selected Images**. When all files have loaded, **click the OK**. You will need to measure as you did for the first. **GO BACK TO PAGE 12 : Measuring the Positions of the Silhouette of the Transiting Planet** and follow the procedure to take measurements of the new photos.

Data will be added to the same data list you started for the first site, with new entries labelled as being from the second site. Once finished you can now view the plots of both tracks on the graphical display window under **Analysis** then **Plot/Fit Data** either on the scale of the full solar disk or as magnified "detail" view.

### Measuring the Parallax between the Tracks and Computing Baseline and Distance Data.

Once you have measured the tracks of the transit from at least two sites, you are ready to measure the parallax of Venus as seen from the two sites. Basically, all you



need to do is select a time when Venus was visible from both sites, and the computer will compute the angular difference between the two tracks. If it is not already open, **open the Analysis---Plot/Fit Data window**. Then on the plot window **select View---Detail** so you can see the plots more easily. The computer connects your measured observations from a given site with a line to produce a track across the sun from each site---you can select either best fit straight lines or a parabola (quadratic) using the **Data---Curve Fit menu** on the plot window. Then select a time to calculate the parallax by using the **Data---Select Observation time** menu item. A slider will appear at the bottom of the screen, and as you move it back and forth you can see somewhat larger circles appear on the tracks which mark the position of the silhouette of the planet as seen from each site. Pick a time in the middle of the observation period when the planet is visible from all the sites. **Click OK**.

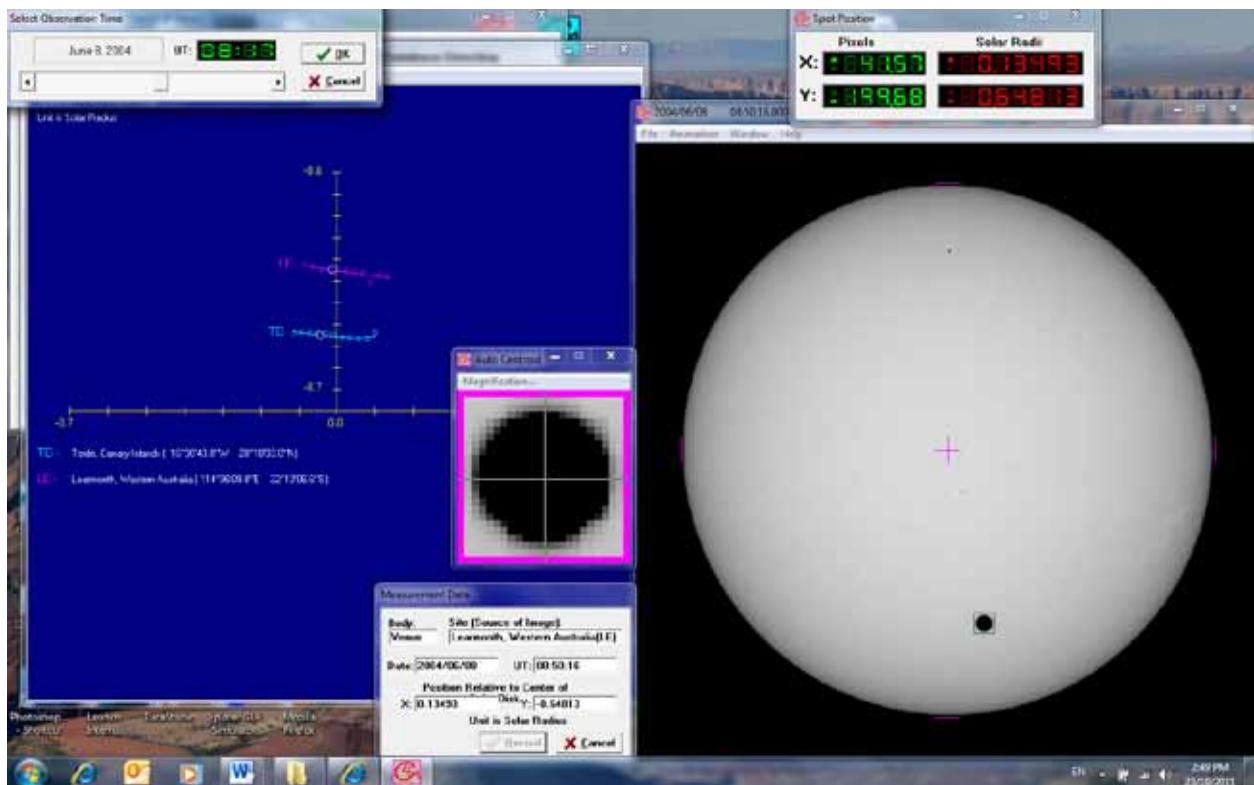


Figure 8: Venus Transit Select Observation Time

Once the observation time has been set, you can now read out all the information you need simply use the **Data---Sun, Planet, Baseline Data choice plot window**, and you will get a window called the **Transit Analysis Ephemeris and Baseline Report** listing all the information you need to insert into the formula for the Astronomical Unit on page 10.

**That information is:**

The “Measured Parallax” in solar radii at the time of observation, which is essentially the distance between selected tracks as seen from a particular two sites. You will need to convert that into seconds of arc using the apparent diameter of the sun at the time of the observation, measured in arc seconds (this is twice the solar radius, of course). Divide the apparent diameter by two to get the radius and then multiply the measured parallax to convert the parallax into arc seconds.

The distance from the Earth to Venus,  $D_{ev}$  at the time of observation, in AU.

The distance from the Earth to the sun  $D_{es}$  at the time of observation, in AU.

The “Projected Baseline”, the distance between the two sites perpendicular to the direction to the sun, measured in km (note that miles are also given, but you want km).

At this point you can print out the data on the report form using the List—Print menu choice on the Transit report window.

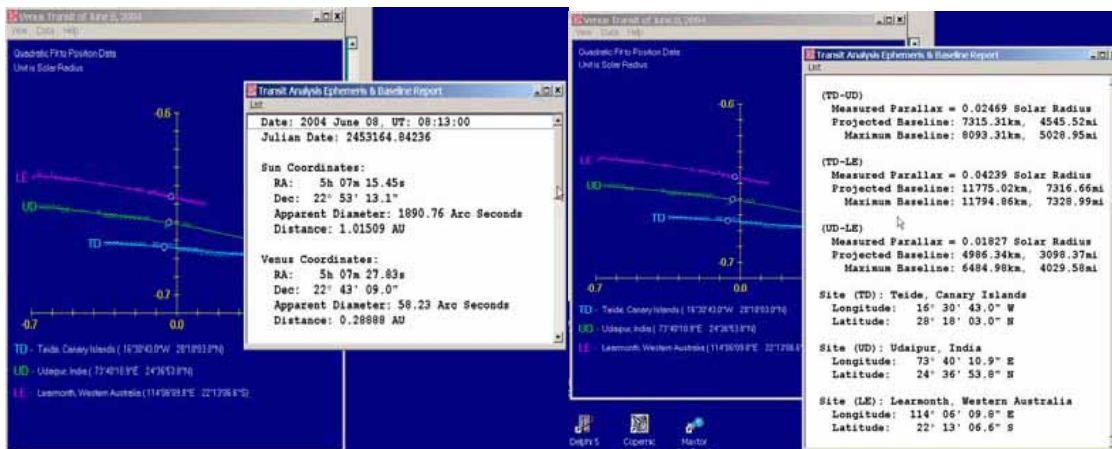


Figure 9: Report windows showing data derived from the observed tracks of Venus across the sun.

*The data can then be inserted into the equation for the Astronomical Unit on page 10, and the length of the Astronomical Unit calculated.*

The simple formula you use to calculate the length of the Astronomical Unit **A** in km is:

$$A = \frac{B \cdot (Des - Dev) \cdot 206265}{\pi \cdot D_{ev} \cdot D_{es}}$$

**CAUTION:** Be sure your units are correct before you plug into this formula. B is in km,  $D_{ev}$  and  $D_{es}$  are both in AU, and  $\pi_m$  is in arc seconds!

**COMPARE YOUR CALCULATION WITH THE KNOWN VALUES OF THE ASTRONOMICAL UNIT IN KILOMETERS.**