The Planetary Transit Special Award

Planetary Transit Special Award Coordinator:

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Big Bear Solar Observatory
14:02:54
34.2584N
116.9213W

The next transit special award is ready for you to tackle.

1. **Mercury Transit 2016 (deadline June 9, 2016)** (jump directly to the requirements)

These Planetary Transit Special Award opportunities have passed and no new submissions are being accepted:

1. Venus Transit 2004
2. Venus Transit 2012

Cerro Tololo Interamerican Observatory
14:02:34
30.17165
70.8009W

Introduction:

Welcome to the Astronomical League's Planetary Transit Special Award site. The purpose of this award is to provide an opportunity to relive the excitement of being on a planetary transit expedition and to derive a value for the Astronomical Unit, and to recognize those who participate. This award is being presented in collaboration with NASA.

Planetary Transits are rare events. They occur when a planet (Mercury or Venus) passes in front of the Sun as seen from Earth. This requires the inner planet be at inferior conjunction along the line formed by the intersection of the Earth's orbital plane and the planet's orbital plane (the line of nodes). Only when these two conditions are met will a transit occur.

Although materials for this program are still being developed, some of the details are known. We will update this site as we get closer to the event and have more details finalized.

*** Safety Warning ***

Observing the Sun can be dangerous if not done correctly. Never look at the Sun directly. Even when it is low on the horizon and doesn't appear to be dangerously bright, it is hazardous. When the sunlight passes through a lot of atmosphere, as it does when it is near the horizon, the blue light is scattered, so less overall light reaches you. But the red and infrared light passes through relatively undimmed and can harm your eyes. So do NOT ever look at the Sun. Use one of the safe techniques mentioned below.

What is a Transit?

Two planets – Venus and Mercury – have orbits that lie inside Earth's orbit of the Sun. When one of these planets passes between the Earth and the Sun it is called an inferior conjunction. When this alignment of Earth, and either Mercury or Venus is nearly perfect, we can observe Mercury or Venus as they move across the face of the Sun. This is called a transit.

Because the planets have slightly different orbital planes, transits do not occur every time there is an inferior conjunction. The last two transits of Venus were in 2004 and 2012. The next two will not be until 2117 and 2125. Mercury, however, transits more frequently. The last two transits of Mercury were in 2003 and 2006. The next two are on May 9, 2016 and November 11, 2019.

What is an Astronomical Unit?

The Astronomical Unit is a measurement that astronomers use to measure distances within the solar system. One AU is the mean distance from the center of the Earth to the center of the Sun. This distance was most recently defined in 2012 by the International Astronomical Union to be 92,955,807.27 miles (149,597,870.7 kilometers). Observers throughout history have attempted to measure the distance between the Earth and the Sun. In the ancient world, calculations varied wildly.

- Aristarchus of Samos, a Greek astronomer who lived from 310 BCE to 230 BCE, estimated the AU to be about 20 times the distance to the Moon, whereas the true ratio is about 390. He is also estimated the AU to be 10,000 times Earth's radius, whereas the actual value is about 23,000.
- Eratosthenes, a Greek mathematician who lived from 276 BCE to 194 BCE, calculated the AU to be roughly 150,000,000 kilometers. This was *amazingly* accurate.
- Hipparchus, a Greek astronomer living from 190 to 120 BCE, estimated the AU to be equal to 490 Earth radii.
- Posidonius, a Roman astronomer who lived from 135 BCE to 51 BCE, calculated the AU to be 63.7 million kilometers (39.6 million miles)
- Ptolemy, a Roman astronomer who lived from 100 CE to 170 CE, calculated the AU to be 7.8 million kilometers (4.8 million miles)

More recently, however, astronomers began to develop much more precise calculations.

- Tycho Brahe, a Danish astronomer who lived from 1541 to 1601, estimated the AU to be 8 million kilometers (5 million miles)
- Johannes Kepler, a German astronomer who lived from 1571 to 1630, estimated the AU to be 24 million kilometers (15 million miles)

- 1635 - Godefroy Wendelin, a Belgian astronomer, calculated the AU to be 89.3 million kilometers (55.5 million miles)
- 1659 - Christian Huygens, a Dutch astronomer, calculated the AU to be 153 million kilometers (95 million miles)
- 1672 - Giovanni Cassini, a French astronomer, calculated the AU to be 140 million kilometers (87 million miles)
- 1771 - Jerome Lelande, a French astronomer, calculated the AU to be 153 million kilometers (95 million miles)
- 1895 - Simon Newcomb, a Canadian astronomer, calculated the AU to be 149.5 kilometers (92.2 million miles)
- 1941 - H. Spencer Jones, a British astronomer, calculated the AU to be 149.67 kilometers (93 million miles)

What is Greatest Elongation?

Greatest Elongation (ε) is the maximum angular distance from the Sun to Mercury or Venus during their orbits. It is the first data point required in calculating the distance of the AU. This can be done by careful observations of the planets over many orbital cycles. You will not actually observe and calculate this, but you will use values from NASA.

Mercury's Greatest Elongation (ε_M) is between 18 and 28 degrees. Venus' Greatest Elongation (ε_V) is between 45 and 47 degrees. The two major contributing factors to this error are the fact that planets orbit in ellipses rather than circles and that the orbital planes of the planets are not exactly the same. For your calculations you will use the median value of 23 degrees for Mercury.

Trigonometry lets us use the Greatest Elongation to calculate the relative distance from Mercury to the Sun (D_{MS}) based on the distance from the Earth to the Sun (D_{ES}). D_{ES} is defined as 1 AU. The equation is:

$$\sin(\varepsilon_M) = \frac{D_{MS}}{D_{ES}}$$

What is Parallax?

You will be using a technique that measures the parallax of Mercury or Venus as seen from two different locations on Earth. Parallax is the difference in the apparent position of an object when viewed along two different lines of sight. It is measured by the angle between those two lines. To demonstrate this concept, extend your arm in front of your eyes and give a "thumbs up". With both eyes open, line up your thumb with a distant target. Now close your right eye; open it and close your left eye. Notice that the target appears to move. This is the parallax effect.

AU Calculation Techniques

There are many approaches used to calculate the value of the AU. Some involve timing the exact length of a transit, noting the exact time the transit began (contact I), or the exact time the transit ended (contact IV). Many of these approaches, including the timing strategies, require very precise observations and very difficult calculations.

This approach will be simpler. You will calculate two distances: D_{MS} – the distance from Mercury to the Sun, and D_{EM} – the distance from Earth to Mercury (during a transit). For this first distance, D_{MS}, you will rely on data from NASA. For the second, D_{EM}, you will rely on observational data using parallax. The sum of and D_{MS} and D_{EM} equals D_{ES} and is a reasonable approximation of the AU.

Calculating the Distance from Mercury to the Sun (D_{MS})

You will use the angle of Mercury's Greatest Elongation (ε_M) to determine the value of D_{MS}, the distance from Mercury to the Sun (in AU). For your calculations you will use the median value of 23 degrees for ε_M.

Using trigonometry you can calculate the distance (in AU) from Mercury to the Sun (D_{MS}) based on the distance (in AU) from the Earth to the Sun (D_{ES}). The equation is:

$\sin(\varepsilon_M) = .3907$ (23°)

$D_{ES} = 1.496 \times 10^8$ km

Requirement #1

$$\sin(\varepsilon_M) = \frac{D_{MS}}{D_{ES}}$$

or

$$D_{MS} = \sin(\varepsilon_m) * D_{ES}$$

$= .3907 * 1.496 \times 10^8$ km $= 58,453,376.82$ km

When you solve the equation for D_{MS}, you will get a number that represents a fractional portion of D_{ES}; a fractional portion of an AU.

Calculating the distance from Earth to Mercury (D_{EM})

You will now use parallax to determine the distance from Earth to Mercury. Similar to the Parallax example used previously, your "target" is Mercury as it transits the Sun, and imagine that your right and left eyes are telescopes at distant locations. In this observational model, if you knew the locations of two observation points and the parallax angle, you can calculate D_{EM}, where B is the distance between the two observation points (in miles or kilometers) and alpha (α) is the parallax angle (the angular distance between the two observations for the transit). Here is the equation:

$B = 8638$ km

$\alpha = .00475$

$$D_{EM} = \frac{B}{tan(\alpha)} = \frac{8638 \text{ km}}{\tan(.00475)} = \frac{8638 \text{ km}}{8.29 \times 10^{-5}}$$

$= 104,197,829$ km

When you solve this equation for D_{EM}, unlike your calculation of D_{MS}, your result will be in miles or kilometers. This is critical because your objective is to express an AU in either miles or kilometers.

Calculating the AU

Mathematically, things from here on are pretty straightforward. Using your equations for D_{MS} and D_{EM}, you can calculate a value for the AU:

$$D_{ES}\ (1\ AU) = D_{MS} + D_{EM}$$

or

$$D_{ES} = (1\ AU) = \frac{\frac{B}{\tan(\alpha)}}{1 - \sin(\varepsilon)}$$

Disclaimer

There are many assumptions and approximations in this process. Your results will vary depending on errors that creep into the process due to factors such as these:

- Planet orbits are elliptical, not circular
- Planets do not orbit in the same plane
- The Sun, Earth, and planet are seldom perfectly aligned
- Your calculation of the AU is based on observations at various points on the surface of Earth. The line connecting the two locations does not necessarily pass through the center of the Earth.
- We are ignoring effects from the Earth's rotation
- We are ignoring any effects associated with the Earth's orbital movement
- You are taking measurements from photos of extremely distant objects

Information on the Planetary Transit: Mercury 2016

The next planet to transit the sun is the planet Mercury on May 9, 2016. Details on transit are available from NASA on this site: http://eclipse.gsfc.nasa.gov/transit/transit.html

Note that for those of us in the eastern United States, the entire transit will be visible. For those in the western United States, the transit will be already in progress at sunrise, so we will not be able to observe the entire event. Timings for the contacts are:

Event	**UT**

• Contact I	11:14, May 9, 2016
• Contact II	11:17, May 9, 2016
• Maximum Transit	14:58, May 9, 2016
• Contact III	18:39, May 9, 2016
• Contact IV	18:42, May 9, 2016

Definition of contact points:

- Contact I: when the leading edge of the planet first touches the edge of the Sun.
- Contact II: when the planet is initially completely on the disk of the Sun.
- Maximum Transit: when the planet is at maximum transit (the middle).
- Contact III: when the leading edge of the planet first reaches the far edge of the Sun.
- Contact IV: when the planet is initially completely off the disk of the Sun.

Mercury is small and so far from Earth and its silhouette is visible only with magnification, but be sure to use proper filters to protect your eyes.

(The next transit after this one is the planet Mercury on November 11, 2019. Mark your calendar.)

How to Safely Observe the Transit:

Observing the Sun can be very dangerous. Be very careful. Never look at the Sun without proper filters. A safe filter must filter 99.999% of the sunlight at visible as well as invisible wavelengths (infrared and ultraviolet). Damage can be immediate and permanent!

Option 1: Pinhole Projection. This is a great, low-tech way to watch the event. It lets multiple people see it at the same time. Do NOT look through the hole at the Sun. Put a small pinhole in the center of a card. Let the light coming through the hole hit a large white card or piece of paper about 3 feet away.

Option 2: Eyepiece Projection. This technique will work for a small telescope or a pair of binoculars mounted on a tripod. Do NOT look through the binoculars or the telescope when it is pointed near the sun! Do NOT do this with a large telescope, the optics may overheat and be permanently damaged. If you are using binoculars, cover one of the objective lenses. Point the equipment at the Sun. Then hold up a white card or piece of paper so that the light coming out of the eyepiece is projected onto the paper.

Option 3: Solar Sunglasses. **Because of Mercury's tiny angular diameter its disk will NOT be visible through Solar Sunglasses.** These sunglasses are easily available on the internet and will be available in local stores as the time draws near. Once you have them, check to be sure that there is no damage. Put them on, and look at a bright incandescent light bulb. You should be able to see the glowing filament. Make sure that there are no cracks, creases, or pinholes. Even a small pinhole will let in a potentially dangerous amount of light from the Sun. It you see any damage at all, do NOT use them. Also note that there are NO sunglasses that are safe for looking at the sun.

Option 4: Binoculars or a Telescope with a Solar Filter. They should have a filter at the **front end** of them. Do NOT use solar filters that attach at the eyepiece end. Make sure that there is no damage on the filter before you use it. Be sure to cover the finder scope.

Option 5: A Solar Telescope. These are telescopes specifically designed for observing the sun usually at specific wavelengths (e.g. H-alpha – 656.3 nm, Calcium K – 393.4nm). I believe that the view in a standard telescope with a standard solar filter will be more pleasing.

Option 6: Shade #14 Welder's Glass. **Because of Mercury's tiny angular diameter its disk will NOT be visible through Welder's Glass.** It is critical that you use shade #14 or higher. The higher number the more filtering. If you are unable to get the shade #14 welder's glass, then we recommend that you use one of the projection methods (options 1 or 2 above). If you combine more than one piece, your total must be higher than 14. Two pieces should total 15. Three should total 16. If you use more than one piece, tape them together so that you will always be sure to be looking through all of the filtering. A higher number is always better.

Requirements to Receive Certification

You must be a member of the Astronomical League as a member of an astronomy club, or as a Member At Large to be eligible to receive this certificate and pin.

Requirement #1: Calculate the Distance from Mercury to the Sun in AU

According to NASA, D_{MS} is 0.387 AU. Calculate this distance using the information noted above. (Note: When you use a calculator or a spreadsheet to do these calculations, be sure that the function you use is working in degrees. If it works in radians, than there is a required conversion: 360 degrees = 6.283 radians.)

Requirement #2: Collect the observations

There are three options available to you. Choose the one that is the most appropriate.

1. You can partner with another member of the Astronomical League who is located at a distance from your observing location.
2. You can observe from your location and get a second observation of the transit from a remote observatory location from the Internet.
3. Or, if you are not able to see the transit on May 9th, you can use observations from two remote observatory locations from the Internet. Observations must be done through imaging.

- Observations should be done by taking images throughout as much of the transit as possible. The times for each observation should be noted (Universal Time).
- Observations from each observing location should be superimposed onto single images to show the path of travel of the transit.
- * The observations from the two different observing locations should be superimposed. To do this, the Sun must be the same apparent diameter in both sets. The point is to show that at the *same moment in time*, Mercury appears at two *different places on the face of the Sun* when observed from *different locations*. You will need to measure the distance between these "same time – different observing locations" images of Mercury for subsequent steps.

Requirement #3: Measure the Parallax Angle

The angular separation of the two observing paths (α, the parallax angle) is also required for the AU calculation. Use the "same time – different observing locations" photo from Requirement #2. At this point, it would be helpful if you worked from a printed version of this image.

Using a ruler (in either inches or millimeters) measure the diameter of the Sun on your printed image. From this, calculate the Sun's radius (which is one half of its diameter). Measure the distance between the "same time – different observing locations" of Mercury. You will be measuring the distance between two dots on the face of the Sun.

You will use this equation:

$$\frac{Sun's\ Measured\ Radius\ (inches\ or\ mm)}{Measured\ Point\ Separation\ (inches\ or\ mm)} = \frac{Sun's\ Angular\ Radius\ (arcseconds)}{Parallax\ Angle\ (\alpha)\ (arcseconds)}$$

You just determined the data for the left side of the equation, and NASA can provide us with the top half of the right side: The Sun's Angular Radius of the sun is 960 arc-seconds. Solving the equation to determine the Parallax Angle (α) results in this equation:

$$Parallax\ Angle\ (\alpha) = \frac{Sun's\ Angular\ Radius * \ Measured\ Point\ Separation}{Sun's\ Measured\ Radius}$$

$\alpha = \frac{960 * 4\ pixels}{449\ pixels / 2} = \frac{3840}{224.5} = \frac{17.1\ arc\text{-}sec}{3600\ arc\text{-}sec/degree}$ or .00475°

Convert the result to degrees (remembering that there are 60 arc-seconds in an arc-minute, and 60 arc-minutes in a degree).

Requirement #4: Calculate this distance between the two observing locations

The distance between the two observers (B) is required for the AU calculation. This can be calculated by using the latitudes and longitudes of the two observing locations. This will be necessary if your partner is working at a distant observing location, or if you are using a remote observatory or two observatories from the Internet. You may use an on-line calculator to determine the distance between the two observing locations. You can find your own tool or you can use this one: http://www.nhc.noaa.gov/gccalc.shtml. This tool will only yield an approximation, but it will be close enough for these calculations.

B=8636 km

Requirement #5: Using the formula and the value you have determined for B, α, and ε, calculate the value of AU in miles or kilometers: (We know that your answer will likely not be close; there are too many sources of error. Submit what you get.)

$$1\,AU = \frac{\frac{B}{\tan(\alpha)}}{1-\sin(\varepsilon)} = \frac{\frac{8638\text{ km}}{\tan(.00475)}}{1-.3907} = \frac{\frac{8638}{.0000829}}{.6093}$$

= 171,012,357 km
= 1.71×10^8 km
12.5% too high

Frequently Asked Questions / Clarifications

I have received a number of questions about the Transit Program. Click here for the clarifications.

$D_{ES} = 1\,AU = D_{MS} + D_{EM}$

D_{ES} = 58,453,377 km + 104,197,829 km = 162,651,206 km

1.63×10^8 km

8% too high

Submit your Results to the AL Coordinator

The Coordinator must receive submissions for this program no later than **June 9, 2016**. There will be no exceptions. A pin and certificate will be awarded to those Astronomical League members who participate.

Actual AU = 1.496×10^8 km

Information Required:

1. Your name, address, telephone number, and email address
2. The Name of your Astronomy Club or "Member-At-Large"
3. The name and address of the person to send the certificate and pin to, if it is different than you
4. Date and Time (UT) of the observations used
5. Your value of D_{MS} from Requirement #1
6. The option you are using:
    a. You and another individual observer
    b. You and a set of observations from the internet
    c. Two sets of observations from the internet
7. The final image of both paths of the transit, marked which path is from which source
8. The Sun's calculated radius in mm
9. The distance between the two observations of Mercury in mm
10. The Parallax Angle (α)
11. Your value for the AU and the units (miles or kilometers)

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