Venus Project Book, the Galileo Project, GEAR   Jeffrey La Favre

You have already learned about Galileo and his telescope. Recall that he built his first telescopes in August of 1609. In the fall of that year, Galileo started to observe the Moon and the following January discovered the four largest moons of Jupiter. His observations of Venus did not occur until the fall of 1610. Why did he wait until then to observe Venus with his telescope?

If you have already worked on the Jupiter project, then you are probably aware that the planets are not always in the evening sky when we would like to observe them. After Galileo observed the Moon in the fall of 1609, he made observations of Jupiter because it happened to be conveniently located in the evening sky of January 1610. At that time Venus was a "morning star," rising just before the Sun in the east. I am guessing that Galileo may have preferred to observe in the evening and was not enthusiastic about getting up early in the morning to make observations. In any case he was busy with his Jupiter observations, which may have consumed all of his available observing time. In January of 1610 Venus was moving away from Earth and was nearly full in phase (85% illuminated). The important crescent phase had ended around the first of October in the previous year when Galileo did not have an adequate telescope to observe it. In May of 1610, Venus passed behind the Sun. The stage was then set for Galileo to observe the changing phases of Venus after it emerged from behind the Sun and made its way closer to Earth in the fall and winter of 1610. In contrast, this year, Venus will pass behind the Sun in June (2016). Therefore, the cycle of Venus this year is about a month or two behind its cycle in 1610/1611.

For the 2016/2017 season, Venus should be observed from October 1 to about March 15. This will cover slightly more time than that of Galileo's observations in the fall and winter of 1610/1611, but will include the various phases of Venus that are important in determining that it orbits around the Sun, not the Earth.   There is a table at the end of this project book that you can use in determining the expected phases of Venus for two dates each month.

Before the telescope, astronomers used only their unaided eyes (sometimes called naked eyes) to view the planets. Even thousands of years ago astronomers were familiar with the peculiar patterns of movement of Mercury and Venus. Both of these planets are always seen in locations in the sky that are not that far from the Sun. That is why we see them only above the western horizon just after sunset or above the eastern horizon just before sunrise. They are never seen high in the night sky like Mars, Jupiter and Saturn.

Most ancient astronomers believed that all the planets and Sun and Moon orbited around the Earth. That is, the Earth was the center of our solar system (a model known as *geocentric*). Today we know that it is the Sun that is in the center. It was Galileo's observations of Venus that helped to prove the Sun was in the center.

While the ancient astronomers believed the Earth was in the center, they did not have an easy time explaining why Mercury and Venus always stayed close to the Sun, while the other planets, Mars, Jupiter and Saturn, would venture far away from the Sun in their cycles. They had to devise complicated models to explain why Mercury and Venus never ventured far from the Sun. Some astronomers did not like these complicated models and preferred a simple model. If we place the Sun in the center, and make Mercury and Venus closer to the Sun than the Earth, then it is easy to understand why Mercury and Venus are never far from the Sun. That is because they have small orbits around the Sun and from our point of observation on Earth, these two planets are always relatively close to the Sun. This was the idea that Nicolaus Copernicus preferred, the *heliocentric* (Sun-centered) solar system. His famous book, **De revolutionibus orbium coelestium** (On the Revolutions of the Celestial Spheres) described a heliocentric solar system and was published in 1543, about 20 years before Galileo was born (http://en.wikipedia.org/wiki/Nicolaus_Copernicus). Galileo and another famous astronomer of the time, Johannes Kepler (http://en.wikipedia.org/wiki/Kepler), helped prove that Copernicus was right.

Now we should describe the phases of Venus and why they prove that Venus orbits the Sun. You are aware that the Moon has phases because you can easily observe them without a telescope (when the Moon is full it looks like a complete circle, at first and third quarters half the Moon is bright and the other half is dark). The Moon looks bright because it reflects sunlight. Therefore, the part of the Moon that is bright is the day time part of the Moon. The dark part of the Moon is dark because the Sun is not shining on it (in other words, that is the night side of the Moon). At full Moon we only see the day time side of the Moon and at the quarters we see half of the day time side and half of the night time side.

Without a telescope, we can't see the phases of Venus because its globe is too small to see with the naked eye (it just looks like a bright star, a pin-point of light). But when we magnify our view of Venus with the telescope, THEN we can see the phases. Venus goes through a set of phases just like the Moon. So let us take a look at a diagram to help us understand what we see in the telescope when we observe the phases of Venus.
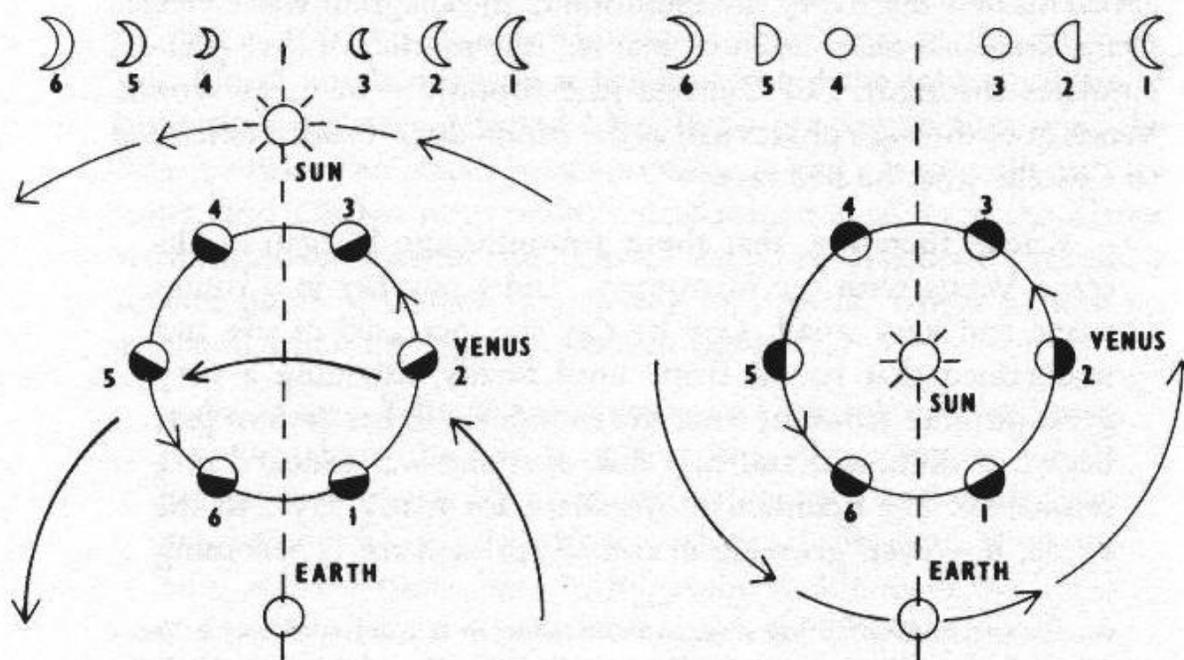
Figure 1 phases of Venus diagrams

The diagram on the left in figure one is a geocentric model devised by ancient astronomers and the diagram on the right is the heliocentric model (the correct model). These diagrams help us to visualize the phases of Venus we would expect to see in the telescope for each model. So let us start with the diagram on the left (the wrong model). This model places Venus between the Earth and Sun, but with both Venus and the Sun orbiting around the Earth. In order to explain the fact that Venus is always near the Sun but sometimes on one side (evening star) and sometimes on the other (morning star), it was imagined that Venus had a compound orbit. That is, Venus orbited around a fixed point in a small circle called the epicycle. And that fixed point at the center of the epicycle orbited around the Earth. In this model we can see that from Earth we would never see Venus in a full phase. That is, it would be impossible for us to see all of the day time side of Venus (full phase). At best we could only see a slender crescent phase.

Now let us consider the correct diagram on the right. In this case both Earth and Venus orbit around the Sun with Venus having a location closer to the Sun than Earth (the correct model). When Venus passes between the Sun and Earth, from Earth we can only see the dark side of Venus (new phase). Slightly less than a quarter of an orbit later we can see half of the day time side of Venus and half of the night time side (first quarter). Then after half an orbit Venus is located on the opposite side of the Sun from Earth. Now from Earth we can only see the day side of Venus (full phase). And then slightly more than another quarter orbit and we see a half-illuminated Venus again (third quarter). It is this phase cycle that Galileo observed in his telescope, which proved that Venus orbits around the Sun. But of course, without a telescope you can't prove this since you can't see the phases.

There is also something else that we should notice. In both diagrams, it should be apparent that the distance between Earth and Venus changes considerably as the planets orbit. But let us just be concerned now with the correct model. When Venus is on the opposite side of the Sun from Earth, it is relatively far away and its globe should appear relatively small in the telescope. As Venus comes closer to Earth, the apparent size of the globe grows. In fact, when Venus is very close to Earth, it appears about 5 times larger in the telescope than when it is on the opposite side of the Sun! That is quite a difference and you should notice this if you do a complete set of observations from full to new phase. Galileo also noticed the change in apparent size of Venus.
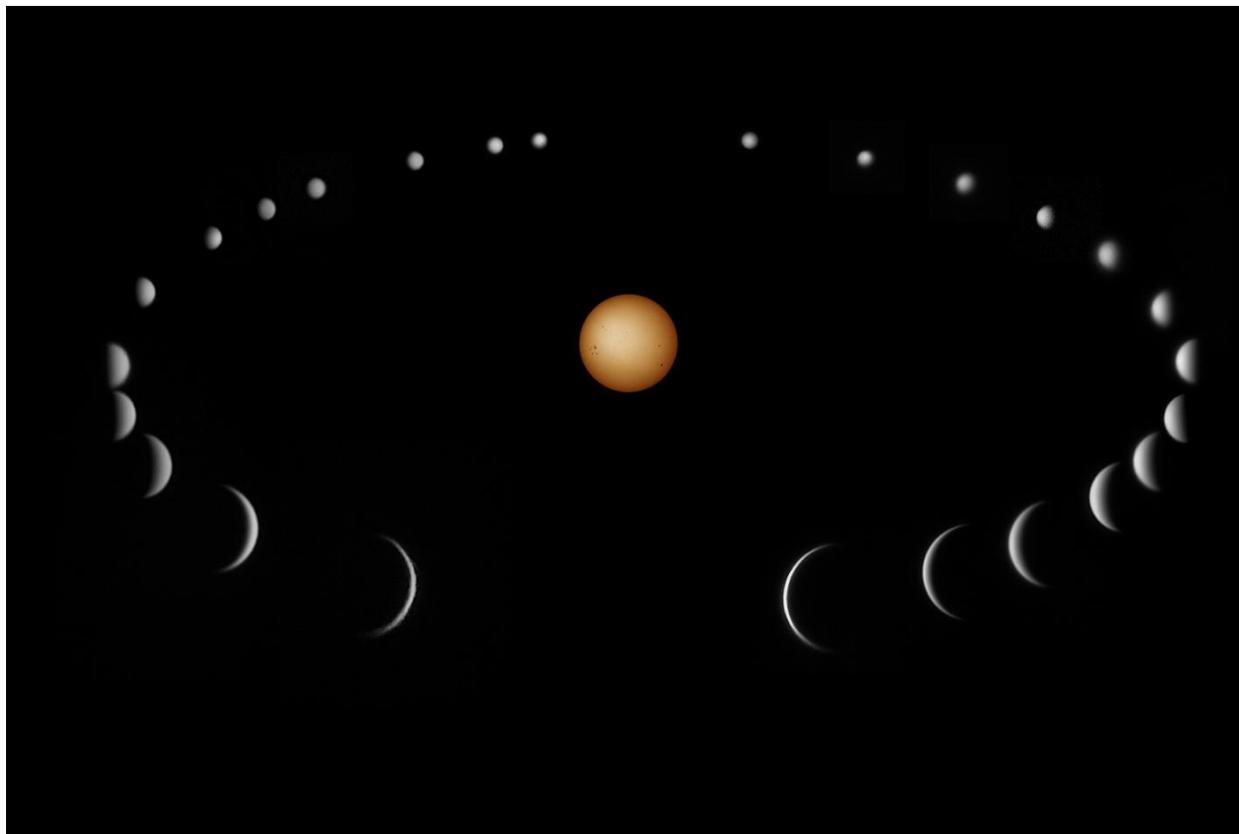
Figure 2 the phases of Venus

The diagram in figure two should give you an idea of the change of apparent size of Venus as it orbits around the Sun.

Now I hope that you realize that there are two important things you should notice when looking at Venus with the telescope: 1) the phase and **2) the relative size of the globe.** The phase will be the easier observation to make, simply draw the phase (like you did for the Moon project). Determining the size is harder to do.

Method One for measuring diameter of Venus

A ruler is used to measure Venus with this method. You have two eyes, but only one is used for looking through the telescope. The other eye can look at a ruler placed on the ground while you observe Venus. This sounds easy, but you may learn otherwise. The trick is to look at two things at the same time, which takes some practice. Shine a flashlight on the ruler so you can see it. While you are looking at Venus in the telescope with one eye, look at the ruler with the other. If you concentrate, you should be able to see Venus on top of the ruler.   Then you can measure the diameter of Venus. I have included a page at the end of this paper that can be used as the ruler. It is a set of heavy bars of black alternating with bars of white. This should work well if you place the ruler on the ground, directly underneath your telescope eyepiece (your telescope must be positioned in such a way that you can look down at the ground while looking though the eyepiece – a refractor with a right angle attachment at the eyepiece will work well….if you are using a reflector, it may be more difficult to achieve the proper placement of the ruler so that you can see it, but it should be possible). In order to make accurate measurements, the ruler must always be the same distance from the eyepiece. Check the distance with a tape measure and adjust the height of your telescope tripod to maintain the proper distance. The actual distance is not important, only that you always use the same distance in subsequent measurements. When making your first observation, measure the distance from eyepiece to the ruler. Then on the following days when you make observations, make sure it is the same distance from eyepiece to ruler.

With this method you are only measuring the relative size of Venus. If you find that the apparent diameter of Venus measures 2 bars on the ruler, then it is two bars wide. But how much is a bar? We don't know that unless we calibrate our method. You could calibrate your ruler by consulting a source of information that gives the apparent diameters of Venus for each day of 2016/2017 or by using astronomy software to calculate the apparent diameters.   I can help you make these calculations.

Method Two for measuring diameter of Venus

Another way to measure the diameter of Venus is by using the **drift method**. Just as the Sun moves across our sky during the day, stars and planets seen at night also move across the sky, from east to west. The cause of the apparent movement is the rotation of the Earth upon its axis. The rate of that rotation in very constant and we can use it to actually measure the diameter of things in the night sky. If you have been using a telescope already, one that does not have a clock drive, you know that things you look at in the night sky move while you are looking at them. That is because the Earth is rotating. We can use the movement we see in the telescope as a way to measure the apparent diameter of Venus.

In order to make a measurement by the drift method, we need to know how fast the object is moving. That gets a little tricky because the rate of movement depends on where the object is located with respect to the celestial equator and the celestial north pole. An object located exactly on the celestial north pole does not move at all. An object on the celestial equator moves faster than anywhere else in the sky. In between the pole and equator, objects move at different rates, faster as the object position is closer to the equator.

On Earth we measure distance from the equator by lines of latitude. For the sky, we use lines of **declination** to measure distance from the celestial equator. The unit of measurement is degrees. There are 360 degrees in a circle. The distance from the equator to the pole is one quarter of a circle or 90 degrees. An object on the celestial equator has a declination of zero degrees. An object at the north celestial pole has a declination of 90 degrees and an object at the south celestial pole has a declination of minus 90 degrees (we can't see the south celestial pole because we live in the northern hemisphere).

We need to know the declination of Venus before we can calculate its rate of movement across the night sky. The formula for calculating the drift rate is given below:

$$Z = 15.0411t\cos(d)$$

Well, unless you have studied the math called trigonometry in high school, you probably have no idea how to calculate a drift rate using the equation above. Not to worry, I will do it for you! But just in case you can do trigonometry, let me first give you the necessary information (Z = diameter of Venus in arc seconds, t= time in seconds for Venus to pass by the edge of field of view in the eyepiece, d = declination of Venus in degrees).

Okay, what is an **arc second**? Well, you probably know that we can divide a circle into 360 degrees. We could say that our sky has a diameter of 180 degrees, which is half of 360 degrees. If we draw a circle across our sky, from the eastern horizon, through the zenith, and then to the western horizon, that would be exactly one half a circle (the other half is underneath us, on the other side of Earth). Well, for astronomers, a degree is a pretty large part of a circle. We need to measure things on a smaller scale. So we divide a degree into 60 parts and call them minutes of arc. There are 60 minutes of arc in one degree. But even a minute of arc is a large amount for astronomers, so we divide it again into 60 parts and call them seconds of arc. There are 60 **arc seconds** in one **arc minute** and 3600 arc seconds in one degree. The apparent diameter of Venus ranges from 9.7 to 66 arc seconds, depending on its distance from Earth.

Before I can do my calculations, I need to know the declination of Venus. Due to the orbit of Venus, it changes declination, depending on where it is in its orbit. Using my astronomy software (SkyX), I can calculate the declination of Venus for any particular time. I have done this in the table below:

Date (in 2016/17)	Declination of Venus in degrees	Cosine of Declination (cos)
November 1	-24.47	0.910
December 1	-23.98	0.914
January 1	-13.68	0.972
February 1	0.77	1.000

Okay, let us work a problem now. Suppose that on December 1 we make a measurement. We watch Venus disappear at the edge of our eyepiece field of view. The time between the moment Venus first touches the edge until it completely disappears we determine by a stop watch and find that it takes 2 seconds. Then what is the apparent diameter of Venus?

The cosine of the declination of Venus on December 1 is 0.914 and our time (t) is 2 seconds:

$$Z = 15.0411t\cos(d)$$

$$Z = (15.0411)(2 \text{ seconds})(0.914)$$

$$Z = 27 \text{ arc seconds}$$

It is actually not that hard to calculate. How did I do it? I multiplied 2 seconds by 15.0411 on a calculator. Then I took the answer from that and multiplied it by the cosine, which for December 1 is 0.914, like this:

$$15.0411 \times 2 = 30.0822$$

$$30.0822 \times 0.914 = 27.4951 \text{ arc seconds}$$

But we did not measure the amount of time to a high degree of accuracy, so we just need to round our answer to 27 arc seconds.

You might guess from my example above that the amount of time you need to measure is very small. It will be just a matter of seconds while you watch Venus disappear at the edge of the field of view in your telescope. It would be best if you had someone help you with the timing. When you first see Venus touch the edge of the field of view, say "start" and your helper can start the stop watch (many digital watches have a stop watch function you can use). Then when Venus disappears completely from view, say "stop" and your helper stops the watch. Then record the number of seconds it takes for Venus to disappear. It would be even better if you could time the event to tenths of a second. That would be tricky and I suggest that you make several measurements and then average them.

When Venus has a phase other than full, you can't see the whole disk of the planet. How can you account for this in your timings? Well, suppose that Venus is at a phase of 50% (half illuminated). In that case, your timing will measure only half the diameter of Venus. Therefore, you will need to multiply your calculated diameter of Venus by two to get the whole diameter. During the crescent phases (less than half illuminated) the tips of the crescent are positioned about half way across the disk. If you can see that very last portion of the crescent disappear then you should be able to treat the disk as half illuminated and multiply your calculation by two as done for the 50% phase.
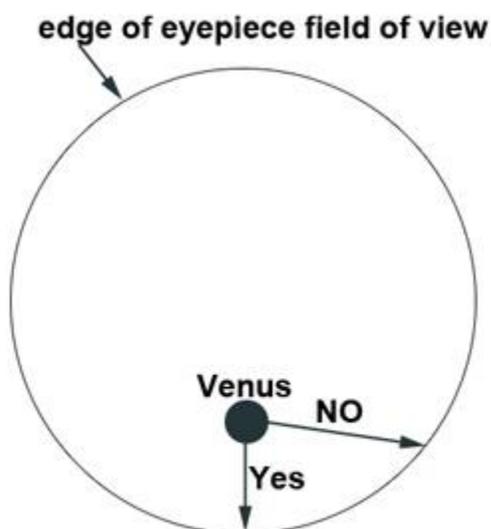
edge of eyepiece field of view

Venus
NO
Yes

Figure 3 proper path for Venus in exiting the field of view in the telescope

One last detail should be accounted for in your measurement of diameter. You should position your telescope so that Venus approaches the edge of the field of view at a right angle (like the arrow marked Yes in the figure to the left). If Venus passes the edge of the field of view at a shallow angle, then it will take longer to disappear and your calculated diameter will be too large.

Another thing you should measure is the distance from Venus to the horizon. Here is the procedure to use. Make all of these observations at the same amount of time after the Sun sets if possible (I would suggest 30 minutes after the Sun sets or the earliest time after sunset when you can easily see Venus). Then measure the height of Venus above the horizon in degrees. You can do this with a quadrant (I have one you can borrow). Why measure the distance above the horizon? With this measurement you are determining the distance of Venus from the Sun in our sky. This helps establish where Venus is in its orbit relative to Earth. Venus is most distant from the Sun in our sky about the time of the quarter phases, which means those are the times when Venus is highest above the horizon at sunset or sunrise.

So, here are the things you should do each time you observe Venus:

1) Draw the phase
2) Measure the diameter of Venus
3) Measure the height of Venus above the horizon at a set time after sunset (for example, 30 minutes after sunset). Instead of observing the time of sunset, you could check a source on the Internet like weather.com

You can record your observations using the form on the next page.

Venus Observations   Observer's Name: _____

Date:_____ Time of Sun set:_____ Height above horizon _____degrees Time of height observation:_____ Phase drawing measurement of diameter of Venus # of divisions on ruler _____ or # of arc seconds _____	Date:_____ Time of Sun set:_____ Height above horizon_____degrees Time of height observation:_____ Phase drawing measurement of diameter of Venus # of divisions on ruler _____ or # of arc seconds _____
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# of arc seconds _____	# of arc seconds _____
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measurement of diameter of Venus # of divisions on ruler _____ or # of arc seconds _____	measurement of diameter of Venus # of divisions on ruler _____ or # of arc seconds _____

Data for Venus – 2016/2017

Date	Phase (%)	Setting Time	Distance from Earth (AU)	Apparent angular diameter (seconds)
October 1	86	20:21	1.38	12
October 15	82	20:12	1.30	13
November 1	78	20:14	1.19	14
November 15	74	19:28	1.10	15
December 1	69	19:57	0.99	17
December 15	64	20:26	0.89	19
January 1	57	20:59	0.77	22
January 15	50	21:21	0.67	25
February 1	40	21:37	0.54	31
February 15	29	21:34	0.44	38
March 1	17	21:07	0.35	47
March 15	5	21:02	0.30	56

AU = astronomical unit = average distance from the Earth to the Sun or about 93 million miles

There are 3600 seconds of angle in one degree

On March 15, 2017, Venus will appear nearly 5 times larger in diameter in the telescope than on October 1, 2016 (56 seconds in diameter compared to 12 seconds)

Ruler for measuring Venus on next page