Smartphone Photography of the Eclipse

Most of the ‘beauty shots’ you will see related to this eclipse will be taken with professional digital cameras on tripods, or shot through a telescope, but the most COMMON photos you will probably see will be taken by the millions of smartphones used by ordinary people to capture this event, and will look like this image (*2015 Eclipse partial phase: Credit:deadmanjones/flickr*). But with a little effort and preparation, you can make photos a lot more spectacular than this!

Here are some general guidelines for taking successful smartphone images, followed by some detailed suggestions.

Safety Issues

There is quite a lot of discussion online about whether you can damage your smartphone camera by pointing it directly at the sun. The basic argument in favor of it being safe for the camera is that the lenses are generally very small (2 millimeters or so) and do not admit enough light. Also, cameras come equipped with UV filters that cut down on some of the visible light landing on the sensor chip. Finally, they automatically set their exposures for very short times.

Nearly every photographer that comments on this issue says it is OK if you do it very briefly such as when you are taking a scenery photo and the sun is in the picture. The argument for it not being safe is that some of the more recent smartphones use larger and faster lenses (f/1.7 to f/2.0) to get better resolution, and that can be a problem.

Most digital cameras have an Auto mode in which they will automatically reduce the exposure speed and increase the f/stop to take the photo, and this will not harm the camera. However, you will need to point the camera at the sun, and you will no doubt accidently glimpse the full-on solar disk and THAT could damage your eyes if you prolong it.

Many of us have taken pictures of scenery on the ground at a small angle to the sun, and all that seems to happen is that the disk of the sun blooms into a distorted glare that can be attractive for some photo compositions. It is a neat image composition effect as you may have discovered accidentally, but again NASA does not recommended you do this on purpose. Besides, there is no reason why you would want to photograph the unfiltered solar disk because you will see nothing but sensor blooming.

The best thing to do is to cover the camera lens with a solar filter during the moments before (and after) totality when the sunlight is still blinding. This will eliminate sun blooming and give you a clear image of the solar disk. You can use one of those ISO-Certified sun-viewing glasses that will be available for eclipse viewing to cover the smartphone lens. DO NOT USE SUNGLASSES! It is a good idea to set up your smartphone on a tripod or one of those wrap-around mountings so that you can fix the angle of the shot before the eclipse starts. The sun disk will be small enough that you will want to avoid the inevitable shaking that occurs when holding the camera. When totality starts, take the filter off and shoot normally with the smartphone. Make sure you take your solar glasses off too during totality because filters will no longer be needed!

You only have 2.5 minutes or less to take photos of the eclipse, but don't forget to take some photos of the surroundings, what people are doing, etc. This will require low light level 'twilight' photography on your smartphone, and you may need to download a specific camera app that let you manually adjust exposure speed, etc. You might also illuminate the foreground with a flashlight or a low-wattage lamp so that it is discernable under twilight conditions. Practice taking photos several days before just after sunset during twilight, because the light levels will be similar if you are on the path of totality. You might even visit the exact spot near the time of the eclipse, but several days before the eclipse, to format your shots and get the right photo composition. The eclipse will happen roughly due-south of your location, so make sure you have a reasonably unobstructed view.

Using optical filters to photograph the eclipse when you are not on the path of totality is inherently risky because you are looking at the blindingly bright solar surface. **NASA makes no recommendations about how to safely photograph the partial eclipse phases because of the huge number of optical filter and camera models that may potentially be used and often with unsafe outcomes.**

Tips

1 – Practice photographing the full moon to get an idea of how large the sun-in-eclipse will appear with your smartphone's lens, or with a telephoto lens attachment. Moon photography is a challenge because the camera will try to automatically adjust the exposure but most of the view will be the dark sky, so the moon's disk will be overexposed and show no details. To get around this, most smartphones let you adjust with your finger where the focus and metering spots will be in the field. There are many smartphone apps that have greater flexibility than the one that comes with your camera, and you should consider testing as many of them as you can before the eclipse to find the right one. Several apps exist for both Android smartphones and iPhones, which claim to enhance your device's picture-taking abilities. The more test shots you can take in the days and weeks before the eclipse, the less time you will waste when the eclipse occurs!

2 - If you are using a smartphone, you need to make sure the image is properly focused. Don't count on your auto-focus to do this. You have to do it manually, and this is as simple as tapping the screen and holding your finger on the moon to lock the focus. Then slide your finger up or down to darken or lighten the exposure. On iOS camera apps, tapping an object will center a box around it and show a little

sun icon. This is the exposure slider. Drag it down until you see details on the moon image. Android camera apps usually have an exposure setting too, but it might take some hunting around to find it. For example, on the popular Samsung Galaxy S5, with the camera app running, tap the gear icon to expand the settings options, tap the gear again to enter camera and video settings mode, and tap again to enter the app's master settings. The Exposure Value control is halfway down the list, and can be slid between +2 (brighter picture) and -2 (dimmer picture).

3 - One effect that you might try to record if you have an unbroken view of the northwestern horizon is the rapid approach of the lunar shadow before it passes over your location at totality. You need to be in a field somewhere with a view of the ground out to the horizon like on a hill or even a mountain facing west. In the distance you will see the ground darken and then in literally a few seconds the sky near you will turn to twilight as totality begins. You will not need a camera filter to see this effect. Then you can look up and see the sun in full eclipse.

4 - Rather than trying to photograph the eclipse itself, concentrate on what people around you are doing, but perhaps with the eclipsing sun in the field of view too. Take a time-lapse photo series of the scenery as the light dims with the smartphone secured on a tripod or other mounting so that you can watch the eclipse while your camera photographs the scenery. You might even want to shoot some video in the minutes before, during and after to record people’s reactions and the inevitable oohs and aahs!

5 - Digital zoom will not work to create a magnified, clear image. Instead, go buy a $20-$40 dollar zoom lens attachment that will give you a total of digital zoom x optical zoom = 12x to 18x. For moon photography in the days and weeks before the eclipse, this will let you see a large moon disk, resolve mare features, and perhaps see a few large craters. At this magnification, the total solar eclipse will also look much nicer because you will be able to start to see details in the shape of the corona!

6 – Consider using the delay timer set at 5 seconds so that once you press the exposure button, the camera waits 5 seconds before taking the shot. That gives your camera/tripod/clamp system plenty of time to settle down and produce vibration-free images.

Specific Suggestions

Your most difficult challenge will be in managing your expectations! Smartphones were never designed to do sun and moon photography. The standard lenses are very small, and provide hardly any resolution at all for even the largest objects in the sky like the sun and moon. These objects are only ½-degree in diameter, and for a typical megapixel smartphone, their disks will only cover a few dozen pixels in your final image. For example, the photo to the left is an enlarged full moon taken by the author with an *iPhone 6s*.

The photo below of the young crescent moon with earthshine and the bright planet Venus was taken by Chris Vaughan using a Samsung Galaxy S4 smartphone.

If you enlarge this image around the moon you get the result shown on the left. You can tell it is the moon, but there is no detail to be seen in the prominent lunar mare, which are easy to see with the naked eye. This image would be very similar to a partial solar eclipse seen through a filter (with the sky black of course!). Nevertheless, the original wide-field photo with the eclipsed sun taking the place of the moon would still be a stunning image to have because you can also capture the scenery and people watching it happen!

Several inexpensive smartphone adapters let you mount your device on a telescope or binocular. These cost about $40.00. If you own a pair of binoculars or a telescope, a simple trick is to hold the camera lens over the eyepiece to achieve greater magnification. Some of the world’s best astrophotographers have used this binocular technique with a tripod to take stunning photos of the moon using just their smartphone. Photographing the sun is a bit more of a challenge because of its brightness.

Many of us have taken pictures of scenery on the ground at a small angle to the sun, and all that seems to happen is that the disk of the sun blooms into a distorted glare that can be attractive for some photo compositions. Here's an example from a free 'wallpaper' website. It certainly looks very pretty in the way that the image was composed, but you do not see the disk of the sun at all.

If you want to image the sun, you really want to at least see the disk of the sun! The only option is to place a properly-designed solar filter in front of the smartphone lens to drastically cut back the light and glare. You will end up with a pitch-black sky and a small disk for the sun as big as the full moon. You will probably want to take these pictures during the hours or minutes before totality so that you can capture the moon cutting into the sun disk. At totality, you can take the solar filter off the lens and take a picture of the eclipse. Once again, the scale of this image will be similar to the full-moon photo you took two weeks before the eclipse. This will give you a sense of scale as you set up your eclipse shots. Many people have posted their attempts at doing this.

This is a typical, digitally-enlarged view of a direct photo through a smartphone. The red halo you see is not the solar corona but simply an artifact of the camera lens and a consequence of the particular f/stop and exposure used by the automatic setup.

You might be tempted to use the digital zoom feature of your smartphone but this is rather useless. All you will be doing is cropping your original image to a format where it magnifies the image. It will not alter the actual resolution of your shot, which is the factor that determines how much detail you will actually see. For that, you have to increase the optical resolution of your camera, which the camera industry calls the optical zoom. For digital cameras like the compact point-and-shoot models or the high-end Nikon D3000 DSLRs, they can provide optical zooms from 2x to 6x by using attached lens systems or by switching to other lenses. For example, a telephoto lens with a focal length of 300 mm will provide 6x optical zoom for a standard 50 mm camera. Some smartphones such as the iPhone 7Plus deliver 2x optical zoom. The Galaxy Zoom smartphones have a variable focal length. For example, the Galaxy S4 Zoom has a 24-240mm f/3.1-6.4 lens. The optical zoom is calculated by dividing the longest focal length value to the shortest one. So in the case of the S4 Zoom, the optical zoom is 10x. Fortunately, for all other fixed-focus smartphones, there are two rather inexpensive ways to add substantial optical zoom capability.

Telephoto Lens Attachment

A telephoto lens system is absolutely a must-have for eclipse photography with a smartphone. There are a number of zoom lenses for smartphone photographers designed solely to provide magnification without resorting to digital zoom. Most of these like the one on the left below, clip directly to the smartphone over the existing lens, and provide total magnifications of 8x for less than $20.00, and 12x at a cost usually under $40.00, but you will need to purchase a tripod for your smartphone to avoid shaking. Some 12x systems like the one shown to the right below include a tripod and a mounting bracket for the smartphone that is far sturdier than a clip-on system. Tripod adaptors for smartphones can be found on the Internet and cost between $3 and $10 brand new, but you can also find them more inexpensively at several auction sites on the Internet.

It is worth pointing out that the magnification touted by smartphone telephoto lenses is not the optical magnification, which is customarily used by astronomers and opticians to describe an optical system. It is common in the smartphone telephoto industry to advertise the maximum product of the smartphone's digital magnification times the optical magnification of the telephoto. It is only, however, the optical magnification that affects the resolving 'power' of the system as we will discuss in a later section following actual measurements of various systems.

At an advertised magnification of 12x, with a digital magnification of 3x and an optical magnification of 4x, the moon disk subtends 4 times as many pixels as a normal 1x camera view, and the optically-enhanced resolution equivalent to a low-power binocular view (e.g. 4x50) results in rather clear viewing of the moon's dark mare features. This image was taken by the Author with a *iPhone 6s* and a 12x telephoto, tripod-mounted.

To rival a binocular view (7x50) you need a telephoto with an optical magnification of 7x or an advertised magnification of 3x7

= 21x or higher. Nevertheless, the properly designed and mounted ‘12x’ system provides images of the moon that are quite adequate for eclipse photography and promises to resolve some of the larger details of coronal structure provided the exposure is in the proper range to avoid coronal over-exposure and burn-out.

This is potentially very dangerous. Only during totality when there is absolutely NO solar disk present and the corona is fully visible can you use the unfiltered telephoto attachment safely. Once the solar disk begins to appear you cannot use the telephoto unless it is properly filtered or you run the risk of shining concentrated sunlight on the camera imaging sensor and potentially damaging it. NASA makes no recommendations on exactly what kind of solar filter you can safely use under these circumstances, but in all applications, the filter must be placed in front of the telephoto lens and not behind it closest to the camera lens. The filter comes first, followed by the telephoto lens and then the camera. If you place the filter between the camera lens and the telephoto, the intensely focused sunlight in direct contact with the filter may melt the filter or otherwise severely compromise its performance providing a hazardous situation.

Binocular photography

If you have a pair of binoculars, you can try one of two strategies: you can have your friend hold the binoculars pointed at the eclipse **during totality** and then position your smartphone camera lens up against the eyepiece, or you can get a binocular-smartphone adapter and a tripod. By the way, if you go for the later approach you will have a fantastic system that you can use for many other photographic opportunities like capturing photos of birds and wildlife, close-up views of sports events or other public activities.

It will be difficult to use the hand-held binocular and camera because there are so many factors that you literally have to juggle to make it work. There will be a lot of movement of the camera and binoculars that will make getting a properly-focused shot hard to take in the short time you have during totality. You will spend so much time trying to set up the shots and line things up optically that you will probably miss seeing the eclipse for yourself!

The only sensible way to do this is to get a binocular attachment for your tripod, and a smartphone lens adaptor for the binoculars. With this set up, all you have to do is point the tripod/binocular at the eclipse in progress, and set the focus on your binoculars and camera once and for all. Then you just need to touch the camera exposure button when you want to take a shot, or better yet, set the camera for video mode!

Binocular tripod clamps are easy to find on the Internet and cost between $10 to $20 for the simple screw-type adaptor, or $25 for the strap-type adaptor that works for nearly all types of binoculars. Remember, this is an investment that by itself will pay dividends later on when you want to observe non-eclipse subjects, so it is definitely not a one-shot investment.

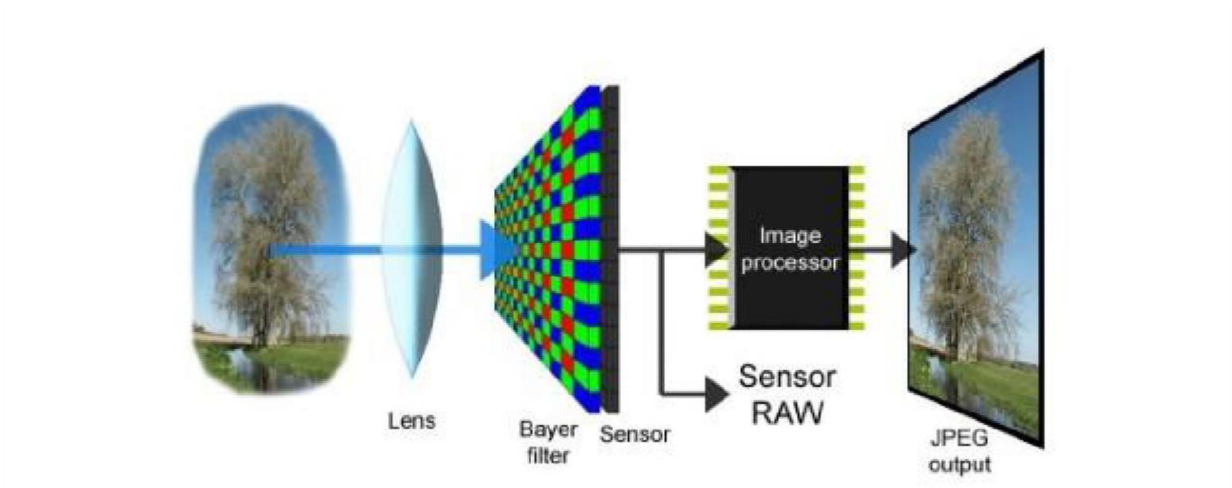
Camera lens adaptors for binoculars can also be found on the Internet and cost between $10 for one designed specifically for your camera type, or between $50 - $70 for a universal adaptor that fits most phone types, and that you can use for telescopes too. All you need to do is use the automatic exposure and focus camera setting and hand-point the binoculars at whatever you want to study close-up.

Caution: If you use the binocular to photograph at other times during the eclipse when the solar disk is blindingly bright, you run the risk of severe damage to the camera unless a properly designed filter is used. This filter must be placed in front of the main binocular lens an NOT between the binocular and the camera. The later configuration will allow the intense, focused light of the sun to fall directly on the camera and either damage the image sensor array, or even melt the camera lens itself. NASA makes no recommendations about which optical filters to use for safe viewing.

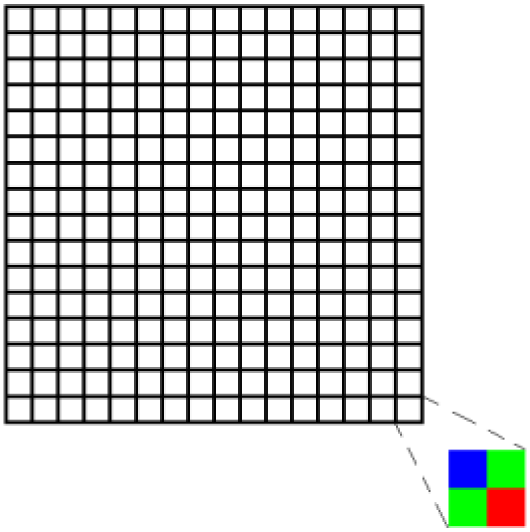
Some Technical Considerations

Camera Sensors and Pixels

The light from a source passes through a lens, then passes through a filter that presents the CMOS array of pixels with a 2x2 patch containing 1 red, 2 green and 1 blue-sensitive filters called a Bayer mask. Each of these 2x2 pixel arrays represents one image 'pixel' to provide the image processor with the information to recover the color of the image pixel. The processor then combines the information from the red, green, and blue-sensitive pixels to create a color image.



The lens is typically about 2 millimeters in diameter, and the Bayer filter and array are both about 1/4 to 1/3-inch (3 to 5 millimeters) in size. Because the physical size of the CMOS sensor changes very little from generation to generation, the increased megapixel size of cameras has to do with the pixel sizes being made smaller and smaller. Current 13 megapixel cameras have pixels only slightly more than 1 micron across. Previous generations of 8 megapixel arrays used 1.4-micron pixels. Will pixels get smaller than this? Probably not. The wavelength of red light is about 0.7 microns so current micron-sized pixels only allow 1 to 2 waves of light to cross their dimensions. For the shorter-wavelength blue light, we are already at 1 wavelength of light, and this is the physical limit of light sensor technology. From now on, it is the physical size of the array that will increase.



By the way, the use of 'megapixel' numbers to describe arrays comes from the product of the pixel width and height of the array, but there is an ambiguity over whether you mean the actual array chip or the smaller number of image pixels after the array has been Bayer filter-binned to create the final image. For example, if the CMOS array has 4 million pixels, each with its own RGB filter, the final image will have only 1 million pixels. Fortunately, powerful software running in the camera's CPU can actually use the Bayer color grid information to figure out or 'de-mosaic' the data and estimate the full color value for each pixel in the sensor array! The end result is that the camera's resolution is better than one would expect if each 2x2 block containing all three colors represented a pixel, but not quite as good as each individual pixel. The real-world resolution limit of a Bayer array is typically around 1.5X as large as the individual pixels.

Camera Resolution Calculations

The quality of the final image is all about what kinds of detail you can see. For some types of photos, you just want to see the sun's corona surrounding the black spot of the moon in the same field of view as the group of friends you are actually photographing. This can be done by just using your smartphone as-is and composing your photo to include your friends with the distant eclipsed sun in the background sky. For other applications, you really want to see as much detail in the corona as you can. In either case, the amount of detail depends on the resolution of your camera system and whether the sun/moon disk covers ten pixels in the final image or 100+. You can figure out in advance which of these cases you will be committed to with your existing smartphone by photographing the full moon in the months before the eclipse (moon and sun have same diameters), or by following along with the calculations and discussion below. In any event, you should probably follow up any calculation with actually going out and photographing the full moon to double check the image scale you want.

Here's a simple and rather direct way to do it from the comfort of your own room. The Author used an iPhone 6s.

Set up a meter stick or a yard stick horizontally on the edge of a table or some other stable platform. From a distance of five feet, take a 1x picture of it, and email it to yourself at its full uncropped size. For example, for an iPhone 6s, this is a 2.8 megapixel file with 3024x4032 pixels. The first thing we will figure out is the field of view of the image. In this instance, a carpenter's 18-inch stick with a width of 48 millimeters was used, and the distance (5 feet) corresponds to 305 millimeters. The width of the image at this distance is 117 millimeters.

From the properties of a right-triangle, the half-width of the image corresponds to an angle from the distance of 5 feet given by the formula: Tan θ = (width/2)/d = (117/2)/305 = 0.192 so θ = 10.86^o and the full-width is just 21.7^o .

The format of the picture is 3024x4032 or 1:1.33 so the angular field-of-view is from scaling just 21.7^o x 28.9^o.

How do we figure out the optical resolution? We photograph the measuring stick with millimeter marks from various distances until we can no longer clearly discern them as distinct no matter how we digitally zoom the image. For the iPhone 6s, this happens at a distance of 7.5 feet or 2286 millimeters. So again from the above formula we now have w=1 millimeter and d = 2286 millimeters so the half-angle is 0.0125^{o} and the resolution is 0.025^{o}. Now, astronomers tend to use arcseconds as a unit of angular measure because most astronomical objects are pretty small in the sky, so this becomes an angle of 0.025x3600 = 90 arcseconds, or alternatively 1.5 arcminutes. Now the resolution of the human eye is about 1 arcminute in the middle of the visible spectrum, so this camera will show a scene at slightly worse than 'retinal' resolution. For example, at a distance of 7.5 feet, a normal human eye would have seen the markings in the meter stick above with a 'bit' more clarity. This difference, outdoors, is not discernable by most people given the varying responses of the human pupil to changing light conditions. It is the available, full diameter of the human eye pupil (larger at night and smaller in the day) that determines your visual acuity.

So what does this demonstration have to do with eclipse photography? For astronomical purposes, the most important factor in any imaging system, be it a telescope or a camera, is its ability to resolve details in the objects being studied. Because objects in the sky are measured in terms of angular units, we have to figure out how well our imaging system can resolve details at a specific angular scale. The basic formula that determines the angular subtence of an object is θ = 206265 diameter/distance, where the diameter and distance are in the same units (meters, kilometers, light years) and the calculated angle, θ, will be in arcseconds. Recall that there are 360-degrees in a full circle. Each degree can be divided into 60 arcminutes, and each arcminute can be divided into 60 arcseconds and 1 radian is an angular measure equal to 206,265 arcseconds. (360 degrees/2π = 1 radian = 57.2958 degrees x 3600 = 206,265 arcseconds). During the August 21, 2017 total solar eclipse, the diameter of the sun and moon are both 1897 arcseconds or just over 0.5 degrees.

What this means is that for our example of the iPhone 6s at its native 1x resolution, its 90 arcsecond resolution will cover the diameter of the sun and moon by 1897/90 = 21 resolution elements. That is the best you will be able to do no matter what 'photoshop' trickery you try to do! The way in which a smartphone's pixels are matched to its maximum optical resolution is actually complicated by the fact that the pixels in the very small CMOS chip are greatly magnified so that they can be displayed on the screen of the smartphone. Manufacturers talk about 'retinal resolution' for their displays but this has little to do with the actual optical resolution of the CMOS sensor! The iPhone 6s boasts a retinal resolution, but as we have seen, the camera resolution itself is about 50% worse than the canonical definition of typical human retinal acuity.

The only way to optically improve the clarity of an image is with the smartphone attached to a telephoto, a pair of binoculars or a telescope. This makes the aperture of the camera lens much larger, and so it decreases the angular scale of the field of view, which is covered by the CMOS array pixels.

I purchased what was advertised as a 12x telephoto lens for an iPhone 6s to see how much improvement I would get. This, by the way, is not really suitable for hand-held operation. The lens clips on to the iPhone over the existing camera lens, but this attachment is very fickle and subject to slippage. You have to remove the iPhone case completely, and through considerable trial and error find the optical sweet-spot where the optical axis of the telephoto lens is aligned with the camera's optical axis.

You also need a tripod to keep the camera from jiggling as you focus and take the exposure. That said, here is an example of the same calculations above. I took the following picture of the carpenter's yardstick as above using a tripod-mounted and focused system from a distance of 13 feet.

On the original image, it is just possible to make out the millimeter separations in this very difficult to focus image, even with a tripod. It could only be done by putting the camera on a 5-second timer because the mere act of pressing the button caused vibrations and blur! So d = 3962 millimeters, w=1 millimeter and so Tan θ = (width/2)/d = (1/2)/3962 so θ = 0.0072° and the full-width is just 0.0144° for a resolution of 52 arcseconds. This is actually no different than using the 1x camera lens!

Next, I purchased a more-expensive *Eco-Fused Universal Smartphone camera lens kit* from Amazon.com, which also offered a 12x telephoto this time supported on the camera by a sturdier mounting clamp. Sensibly, the kit comes with its own table-top tripod, which is a hint that this is not recommended as a hand-held instrument. I determined its optical resolution by going outdoors on a sunny day and placing a meter stick at a distance of 44 feet, at which point I could just make out the millimeter gradations on the original image.

So d = 13411 millimeters, w=1 millimeter and from Tan θ = (width/2)/d = (1/2)/13411 so we have θ = 0.0021° and so the full-width is just 0.0042° for a resolution of 15 arcseconds. It is common for imaging systems to use 2 pixels for each resolution element (called Nyquist sampling) so this corresponds to a digital resolution of about 7.5 arcseconds/pixel.

On the left is a photo of the moon taken with this ‘12x’, tripod-mounted system with my *iPhone 6s*. I again used the 5-second delay timer to eliminate jitter and took a series of 5 photos selecting best of the batch to get the best atmospheric conditions. If I compare this 6x image with the image taken by Fred Espenak on the right (effective resolution of 7.5 arcseconds/pixel) it is clear that this relatively inexpensive telephoto system for the smartphone will produce exceptional ‘close-up’ eclipse photos even for the discriminating amateur astronomer!