WRITE-UP DUE IN CLASS MAY 13th, email pictures before then (both raw and measured).

The Rules about the pictures: For part I of this lab, you were supposed to obtain digital photographs of the moon, preferably on the same night, both high in the sky and down near the horizon. If you did not do this in the first week the assignment was handed out, you may not have been able to obtain pictures before the weather turned and the moon progressed into/past 3rd quarter. Welcome to the world of astronomical observing!

- If you obtained your own photographs and analyze them, you will receive extra credit on this assignment (even if they do not actually work—as long as you analyze them correctly).
- If you did not obtain your own photographs, or you are not happy with the analysis results of your own photographs, you may download photos I have taken from the course web site.
- To get the extra credit, you must analyze your own photos, even if you analyze mine also.
- You must email me your raw photos, including the calibration image from the classroom, so I can check them out and make sure the lab will work for your data, and also you must email me the copies of photos you are making measurements on (see below).

While the lab is probably easier to do with a full or mostly full moon, you can still do it with pictures of the waning crescent or a waxing crescent—the moon will be heading back towards first quarter past May 7 or so. In fact, as some of you have already discovered, it is a lot easier to get a good picture of the moon in partial daylight. Therefore, I encourage everyone who missed the moon so far, or ended up with very overexposed photos, to keep an eye out and try to get even just one of their own photos and include an analysis of your own work in this lab even if the moon is in crescent phase. However, in the meanwhile I recommend doing the analysis on my photos or any photos you already have—it will be easy and fast to repeat the steps after you have done them once.

The analysis goals

You will:
- use the classroom picture to determine the scale of your photos in arcminutes / pixel.
- measure the size of the moon in pixels and convert that to arcminutes,
- determine the error of that measurement,
- use the angular size-distance relation to determine the distance to the moon based on the size you measure,
- compare that result with the actual distance to the moon at the time of your photographs,
- explain any discrepancy in the numbers,
- compare the size of the moon low to the horizon with the size of the moon high in the sky.

You will need access to some kind of an image editing program to do a couple of the steps in this analysis. Something as simple as "Paint" included with Windows will do; talk to me if you run into trouble. Also, carry through at least 5 or 6 digits until you get to your final answers (487.68, not 488) to remove effects from rounding errors.

Write up a lab report of your results neatly on separate paper. Explain what you are doing for each step. As explained in the instructions to part I, my original intention was for you to use the known distance to the moon to determine the physical diameter of the moon (in the angular size formula, the variables are the angular size of the object, the physical diameter of the object, and the distance to the object; from any two you can solve for the third, and the distance to the moon is measurable through variety of means). However, it will be easier to do the lab if we consider the diameter of the moon to be known (because it does not change), and instead you solve for the distance at the time of your observation (which does change over time). Astronomically speaking, this is actually a pretty useful thing to know, because if you repeated your observations over time, you could build up a model of the orbit of the moon.

(1) Data: The first section of your write-up should describe the camera you used, the time and date of the photos, and any other relevant information or observations. Also include that the diameter of the moon = 3476 km  (e.g., see Appendix E, table A-16).
(2) Prepare your image(s).
You will need to count the height of the moon and part of the meterstick in pixels. You will need image editing software to do this. Before you start counting, (a) make sure you have emailed me the pictures you are using, (b) save a copy of the pictures to edit so that you don't lose your originals. [Note: the images below are NOT at the same scale as the ones provided on the link, they are for illustration purposes only!].

Counting pixels may seem tedious, but there is an easy way to do it even for high resolution images. Load the image you are working with into the image-editor. I include here pictures and steps from using Paint on a Windows machine; there are equivalent and better tools in any image editor. Zoom in near the object you will be measuring, and—a bit away from the object—start drawing a pattern like the ones shown below, using a pencil tool. Alternate columns for each pixel and make the longer lines at increments of 5 and 10. Once you have 20 or 30 drawn, you can copy what you have and paste it below to extend the scale (left figure). Once you have a sizeable scale, copy and paste that over or next to the object you want to measure (right figure), and repeat if necessary.

You can create a new scale (probably in red or some color, not black or white) to measure the moon in the moon images, or if you are careful not to change the size of the regions, you can even copy out a box around the moon(s) in your moon photos and paste them right into the copy of the meterstick image, and use the same scale for all. Pasting them into the same picture is also a good way to compare the size of the moon low and high in the sky. Come see me in if you encounter problems making these measurements or have questions.

(3) Determine the scale of your photograph
An accurate version of the angular size formula is \[ \frac{A}{360} = \frac{l}{(2\pi d)} \] where A = angular size, l = physical length, d = distance.

We can simplify this by dividing by 2 \( \pi \): \[ \frac{A}{57.29577} = \frac{l}{d} \] It will be easiest to do the lab if we use arcminutes instead of degrees, so let's multiply the 57.29577 by 60' per degree: \[ \frac{A}{(3437.747')} = \frac{l}{d} \]

We will use this later to find the distance to the moon. Right now, however, we want to find out how many arcminutes tall each pixel in your images is. To do this, we first need to know how many arcminutes tall something in the calibration photograph is.
The white and orange markings on the meterstick from class are 10 cm long. The distance from the meterstick to where the pictures were taken was 5 meters (or 500 cm). Solve for the angular size of one of the colored sections of the meterstick. (This should be written out in your write-up)

Count the number of pixels for one or more sections of the meterstick, depending on how big it is in your image. Do not use the very top section of the meterstick—it is not quite 10 cm. Email me the image with the scale pasted in. Determine how accurately you think you can measure the edges of the region of the meterstick you are using—one? two? five pixels? If the meterstick is highly tilted in your image, you can measure vertical and horizontal distances and use the pythagorean theorem for the distance along the meterstick.

Check the percentage uncertainty on your measurement:

\[
\text{uncertainty in pixels / total length in pixels} \times 100\% = ?
\]

If this is more than 1%, you should measure over more segments of the meterstick (your uncertainty will stay the same, but the total length will increase). Record the percent uncertainty for the measurements you use.

Calculate the plate scale of your photo in arcminutes per pixel by dividing your result from A by that from B.

Measure the size of the moon in pixels.

If the moon's edge is not well-defined, for example, if there is a very solid region and outside that a region of a different color, or a halo, or some other effect, you may want to record a couple of different measurements.

If the moon is not full, make as good an estimate as you can of where the full diameter should be. Make measurements for the low and high moon in the sky (if you have both data sets). Estimate the uncertainty in your measurement (in pixels). Explain the limiting factors.

Email me a copy of your "measurement" image with the pixel scale pasted over the moon.

Using your plate scale, convert the measurements in pixels into measurements in arcminutes. Since we are just multiplying by a constant, you can directly convert the uncertainty in pixels into an uncertainty in arcminutes, e.g., for 50 +/- 2 pixels (% uncertainty is 4%)

\[
\begin{align*}
50 \text{ pixels} \times 0.10' / \text{pixel} & = 5' \\
2 \text{ pixels} \times 0.10' / \text{pixel} & = 0.2'
\end{align*}
\]

answer: 5' +/- 0.2' (% uncertainty still 4%)

At this point, we can address the secondary goal of the experiment: are the sizes of the moon in the two images significantly different for low and high in the sky?

If so, do you believe the effect is real, or some kind of artifact of your experimental data (explain)?

If not, why do you think people often think the moon is much large near the horizon?

Determine the distance to the moon.

Use your best measurement (with uncertainty) of the angular size of the moon from (4).

Solve the angular size-distance formula for the distance to the moon in terms of its physical diameter and the measured angular size, then calculate the distance to the moon in kilometers.

Calculate the uncertainty on this result in kilometers:

1 - determine the percentage uncertainty on the angular size measurements
2 - take that percentage of the distance you just calculated in A; this is the uncertainty in km.

Compare the distance with the actual distance for the time of the photograph you are using.

There are a couple of ways to come up with this number. One, you can try using a planetarium software program like Stellarium or Starry Night (if you know someone who has it), set it up for a location nearish to Amherst (Holyoke
is a pre-set), set the time and date to when you took the picture, select the moon, and it will tell you the distance. Two, you can come to office hours, and I will show you how to do this on one of my computers, it will take about 5 minutes (you could probably do this before class time, too). Three, you can write me, and I will look it up for you. Four, you can try to find the distance to the moon on the day you took the photos by searching the web for the info. Five, you can assume that the value is close to the apogee of the moon's orbit, which was 405944 km on April 23rd, if your photos are from then. Since the moon's orbit only takes a month, it will be quite a bit closer at perigee two weeks after April 23rd, so it's going to work better if you try one of the first four choices.

(B) Calculate:
1 - the difference between your number and the distance that day. Is this number smaller than the uncertainty in km you calculated in part 5B? Is it smaller than twice that value?

Basic "Gaussian" statistics hold that two numbers "agree" if the difference between them is less than two times the uncertainty (usually referred to as "sigma"). Do your experimental results agree?

2 - the percentage error of your result and the distance that day. How does this value compare to the percentage uncertainty on the angular size measurement and to the percentage uncertainty in the plate scale?

(C) Comment on your results. If the distance is very, very different, explain what you believe is incorrect with your pictures. Provide details and/or try repeating the analysis on my photos.

(7) Another effect to consider

(A) Does the distance to the Moon change over the night?
(B) Is the moon closer or farther when it is at the meridian vs. rising or setting? Should it look bigger or smaller?
(C) Do your observations agree with this expectation?
(D) If you were on the equator, roughly how much would the change in distance be in km?
(E) What percentage of the total apogee distance of 405944 km is this?
(F) Is this effect larger or smaller than your plate scale percentage uncertainty? Would you be able to observe the change due to this effect?

The purpose of this lab is to do something practical, and at least a little interesting--you really are making a direct measurement of the distance to the moon, with your own camera. Along the way, you are going to encounter some real problems in science with instruments, timing, weather, equations, detailed effects, uncertainty, and the unexpected. That's also part of the purpose, to see what this is really like. But if you get stuck, get in touch with me sooner instead of later, because I want you to find your way to results that make sense! Feel free to email me any intermediate results or calculations you may have if you want to check that you are on the right track.