**SKYLABS (Fall 2017)**

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[adapted]

**Introduction**

Included in this handout are six possible term papers: you must choose one of these to do at some point during the quarter. Five of these are outdoor observing exercises, one is a fall-back project if bad weather should become an issue. The objective of the Skylabs is to give you a taste of observing nature, taking data, understanding uncertainties in measurement, and writing in the scientific style. The rest of this introduction describes how to do these Skylabs.

**I. Communicating your results**

Communication is an important skill in science, as it is in all other fields of endeavor, for if scientists do not communicate their results to colleagues, the work is wasted. Scientific writing is generally simple and succinct. Data should be presented in a way that is clear and easy to understand, usually in the form of a table or in a graph. A sample of what a data table might look like is shown on the next page. If you consult any books or articles in the course of preparing your Skylab, you should cite your references using any format for the references you are comfortable with. (If you would like to try the style common in astronomy, it resembles the APA documentation style described in the *Keys for Writers* handbook. For more detailed guidance on documenting your references, consult any writing handbook.)

Your report should take the form of a short paper (between 4-6 pages), divided into the following sections:

1. *Introduction.* State the objectives of your measurements.

2. *Procedure.* Give a careful description of your procedure, including the date and place of your observations. What materials did you use? How did you take your measurements? (What would another student have to do to repeat your measurements?)

3. *Description and presentation of your data.* Your tables and graphs may be incorporated here, or attached as an appendix. Be sure to explain in words what the data in your table represents. A list of numbers with no explanation is not very informative!

4. *Answers to the questions accompanying the Skylab*.

5. *Conclusions*. Here you tell the reader what you have learned about both the heavens and about how take observational data, spotlighting any particularly interesting or unexpected results.

You may also mention any new questions your results raise and any suggestions you have for better ways that future astronomy students might carry out such a Skylab.

Each of these sections should contain at least a full paragraph of writing, with the possible exception of your answers to the questions in section 4 – these you can leave as a numbered list.

**Table 1. Measurement of azimuth angle and shadow length: example of a data table**

Time (EDT) angle shadow length comments

(degrees) (cm)

8:05 AM 300 55.6

9:00 310 47.8

10:10 320 35.2

11:10 — — sun covered by clouds

11:40 335 25.3 sun’s first appearance since 10:30

   [more data]

1:10 PM 0 21.7 Stick knocked over; set back as

straight as possible

1:30 10 22.9

   [more data]

7:35 80 67.7 sunset

**II. Recording data**

When you make an observation or conduct an experiment, you must record all the relevant variables, or you risk your results being worthless. In astronomy, you must record not only the values you measure (the altitude of the Sun above the horizon, the position of a planet in relation to the stars, or whatever), but also the date and time of the observation (specifying Eastern Daylight Time, Eastern Standard Time, or maybe even Greenwich Mean Time) and the observing conditions at the time (clear, hazy, broken clouds, glow from city lights, etc.).

**III. Errors**

Every measurement is unavoidably subject to error, due to factors beyond the experimenter’s control – vibrations from a truck outside might make an indicator needle jump while you’re reading it, for instance. It is important for a scientist to make a good estimate of the possible range of error (called *uncertainty*). The conclusions you reach in your experiment are only as good as your estimate of the uncertainty involved. Having very small uncertainties relative to your experimental values is not necessarily a measure of how well you did the lab (though you should try to minimize errors as much as possible).

Why should you have to worry about errors so much? What’s important is not your measurement *per se*, but the true value of what you’re trying to measure. Thus, your experiment is only useful insofar as it puts limits on the true value. Without error bars on your measurement, you aren’t saying anything about the true value. For instance, you might think you are being very precise if you say that your measurements indicate that a certain wavelength is 376.5 nm; but everyone knows that this isn’t the exact wavelength, because no measurement can be perfect. How close is the real value to 376.5 nm? You haven’t said! If, on the other hand, you say that your measurements indicate that the wavelength lies between 376.4 nm and 376.6 nm, you’ve actually made a much stronger statement.

In the world of astronomy, people will be convinced by your work only if they respect your error analysis. If you do a poor analysis, no one will give your results much credence, and they will ignore the fact that you ever did the experiment. That is a terrible feeling for an experimenter, especially if you’ve spent thousands of dollars and months of your life working on it. The same thing goes in the “real” world, by the way. Say you are measuring the resonant frequency of the wings of a DC-10 aircraft. Suppose you measure 600 per second and don't bother to calculate the error bars. An engineer assumes you mean 600 ± 1 per second and adds a system which runs at 630 cycles per second. Suppose your real error bars were ± 200. What happens? Hundreds of people die when the wings break off. Clearly, people will be interested in how far they can trust your experiments.

*Types of error.* There are two types of errors, systematic and random. Systematic errors arise when we consistently perform our measurements in such a manner that they are biased in a particular direction. For example, an observer may measure the magnitudes of some stars or galaxies and publish them, only later realizing that a new campground had opened upwind, sending smoke over the observatory every night, artificially dimming the objects. If you don’t take this possibility into account as part of your data reduction, you could be in for a nasty surprise. Such errors can be very difficult to recognize. The best way to avoid systematic errors is to be very careful in the way the measurements are made (in the example, you would avoid this problem by observing “standard” stars every night to calibrate the brightness of other stars).

Random errors are the errors that can never be eliminated, only minimized. The best way to estimate the size of the random errors is to repeat measurements many times. In general, we get a slightly different value each time the measurement is performed. The differences between these values provide an estimate of the error. For instance, if you measure the size of your room with a ruler, you may lay the ruler down differently, or you may read it differently. Suppose you measure 130.5", 132", and 131.5". You would take the average of these numbers, 131.3", as your answer. The range of values, 1.5" (the difference between the maximum and minimum values) provides you with some measure of the uncertainty of each measurement. (Scientists usually use a different measure called the standard deviation.) The more measurements you take, the more accurate your average will turn out to be, because if the errors in the measurements are truly random, they should just about cancel each other out in the averaging process.

Remember, error is not something magical which no scientific laws govern. True scientists recognize that error doesn’t come out of thin air, but always has a mechanism causing it, a source. If they see discrepancies with the values quoted in textbooks (“book values”) outside the limits of their errors, they look for a physical explanation. Maybe a new or overlooked effect is at work; maybe one is discovering new science! (Also, the book values are not written there by an omniscient being — they also have uncertainties.) Paying careful attention to little discrepancies and reducing the error bars sufficiently to discern them are primary qualities of a Nobel prize winner.

*Estimating your uncertainty.* Finding the sources of error is not always easy. However, if you list every possible variable that might affect your measurement, you have all the variables that can produce error. Then you need only go through the list, and for each variable that you don’t have control of, estimate how much error it introduces.

If your error is random, you can repeat your measurement many times, and see how much your results vary. However, you may not have the time (or money) to repeat your experiment many times. In that case, you must use other methods to determine the uncertainty of your measurement. It is simple in the case that your measuring instrument has a known uncertainty. For instance, if you use a wrist watch to measure time, you most likely cannot read the time to better than one second (and perhaps it takes you another second to move your head to look at it). In more complicated measurements, you can deliberately change the variable causing the error and see how much your results change. For instance, if you think that changing your location will change the time a star passes behind a building, which is what you are trying to measure, you can deliberately move a step or two to the side and see how much your measurement changes.

**IV. Significant Figures**

The question of the number of significant figures in one’s measurements is closely related to that of error. For example, consider a simple homemade quadrant. With such a device we may be able to measure a star’s altitude above the horizon to the nearest half degree. Thus we might record a measurement of 35.5 degrees. This measurement has three significant figures. To quote a measurement of 35.52 degrees made with such a device is misleading, because you don’t really know what the last digit is. Such an instrument simply cannot measure angles to a precision of 0.01 degrees. However, if we were to use a navigator’s sextant, we might indeed fairly measure the altitude to be 35.52 degrees. Because of this instrument’s higher precision, we are justified in quoting four significant figures.

When combining measured quantities through arithmetic calculations, the final result should be expressed with no more significant figures than the quantity with the least number of significant figures. For example, if we have three quantities of 25.1, 37.22, and 44.33 and multiply the first two and divide by the third, our answer is 21.1, with three significant figures. We are only fooling ourselves if we read off the calculator and then write down 21.07426122, or even 21.07, since a chain of calculations, no differently than a chain pulling an auto out of a snow bank, is only as good as its weakest link.

**V. Working with others**

Many students like to work in groups while carrying out their observations (even astronomers are like this... who wants to spend an entire night alone in the dark and in the middle of nowhere in the name of science?). You may work together in groups of up to 4. Each group should hand in one written report of your project.

**VI. Observing Conditions**

For the experimental Skylabs (1-6), you want to have adequate observing conditions. Typically, you want a site with dark, open skies that you can easily identify if you have to do multiple observations at different times. Also, look up the dates for **full moons** in autumn quarter before you observe. The full moon makes observing dim celestial objects more difficult, since it brightens up the sky considerably.

**Skylab #1**

**“Now Where Was I?”**

Introduction: One might think that the Sun and the stars move across the sky at the same speed since their motions result primarily from the same cause—the rotation of the Earth. The Sun’s apparent motion, however, is also affected by the orbit of the Earth. Because we travel around the Sun, we must complete a little more than one rotation for the Sun to appear in the same place on two successive days. On the other hand, the Earth is so far from the stars that its motion among them is negligible, and a given star will appear in the same place for every rotation of the Earth. The time required for this rotation is called a sidereal (star) day.

Equipment: One good eye, a tall building and a watch (must have a seconds hand or a digital display).

Time Required: A few minutes on each of several nights over a week or two.

What to Do: To find the difference between a solar day and a sidereal day, you will measure the intervals between the times when a star[[1]](#footnote-1) returns to a given spot over successive evenings. This requires knowing both the position of the star and the solar time when it is in that position. The latter is easy—you can read it off your watch, although you should carefully check your watch before each observation to make sure it isn’t gaining or losing time each day.

Finding the position is somewhat trickier. Note that you don’t really need to know the coordinates of the position; you need only to pick a spot which can be reliably identified each night as the star returns. A good way to do this is to time when a star passes behind (is occulted by) a tall building. The edge of the building defines the spot. This would be fine if you could remain at the same location for several nights. But if you must leave during the 24 hours and you then return to a slightly different location, the edge will be in front of a different place in the sky, resulting in a poor measurement.

To minimize this problem, move as far away from the building as possible. For example, if you think you can from night to night reproduce your observing location (position of your eye) to within 1 meter, the building should be at least 100 meters away from your spot. For ½ meter, the building should be 50 meters away, etc. A good way to mark your position and sight-line would be with a stick, but this is not necessary if you are careful.

Pick a bright star low enough in the sky that it will soon be occulted by your chosen building from your vantage point. It’s simplest if the star is roughly in the southerly direction; if it is not, you will have to think carefully about the star’s path across the sky. The best thing to do is to monitor the motions of a few candidate stars over an hour or so, and thus better pick a suitable star, building and observing location.

Having chosen those, record the instant at which the star is occulted by the building. If you want to improve accuracy, you can repeat this for a second star, which wouldn’t have to be using the same building or even the same observing location. On the next clear evening, return to exactly the same observing location, find your star, and again record the time of occultation, down to an accuracy of at least a second. Repeat this on at least three nights, but 4-6 nights and a longer interval between nights yields better accuracy.

Questions:

(1) Calculate your values for the length of the sidereal day for each of the night-to-night intervals for which you observed.

(2) Determine at least four sources of error in this experiment and for each, list a way, if one exists, for that error to be minimized. Also, estimate the size of each error (in time) as best you can. I’m not expecting a full-blown statistical analysis or anything... but do your best to make a reasonable estimate.

(3) To find the total estimated uncertainty in your experiment, it is not quite correct just to add up the individual errors. You must square each of the errors you calculated in part (2), add the squares, and take the square root of the sum. (Ask for help if this instruction isn’t clear.)

(4) Compare your average measured value with its estimated uncertainty with the accepted value. Don’t work backwards here! In other words, give me your honest opinion of your error bars, whether they turn out to be unreasonably large or small...what counts here is that you do the science honestly without letting yourself by biased by trying to get just the right numbers. That’s the whole point of this process! State whether the actual value falls within your error bars, and state whether you think your error bars were satisfactory.

(5) Usually, your longest intervals between measurements will give you the most accurate results. Why is this?

(6) Why does standing further away from your occulting object reduce the error? Explain with a diagram if that will make your case clearer.

(7) Make a sketch showing your set-up with approximate measurements of distances. Also, identify which star(s) you used using a star chart. Just the name(s) and rough coordinates will be fine.

(8) Should your measurement differ from star to star? Why or why not?

Be sure to follow the format described in the introduction in writing up your results.

**Skylab #2**

**“Road Trip!”**

Introduction: Eratosthenes was a Greek scholar in the Egyptian city of Alexandria, the great center of learning of the Mediterranean world in the days of the ascendancy of the Roman Empire. He is credited with having applied simple geometric reasoning to obtain an excellent estimation of the Earth’s circumference. With very simple instruments, you can make a similar observation today and measure the Earth’s circumference without going all the way around the world.

Equipment: A stick at least one foot long which can be driven into the ground (or a “plumber’s helper”), a measuring device (tape measure or ruler), a carpenter’s level, possibly a flat board or piece of cardboard, a watch and a way to get somewhere else (car, bus, plane, whatever).

Time Required: Two days when you can make observations of the sun’s altitude between 11:15 AM to 12:45 PM Eastern Standard Time (12:15 PM to 1:45 PM Eastern Daylight Time). One of these days should be in Columbus and the other day at least 150 miles north or south of Columbus, say in Detroit or Lexington. You need not go exactly due north or south, but the experimental results are easier to interpret if you don’t wander too far east or west. If necessary, the observations can be made several days apart, but this will require some corrections, so it will be easier to deal with your data if you can do this on consecutive days.

What to Do: Drive your stick (gnomon) into a level, smooth (ideally no grass) piece of ground, making it as close to vertical as possible. If the ground is not level, use a board or piece of cardboard to cast the shadow on. Use the carpenter’s level to make sure the board is level and the gnomon vertical. Beginning about 11:15 AM EST (12:15 PM EDT), carefully measure and record the length of the stick’s shadow every 10 minutes. Continue this until you are certain that you have observed the shadow at its shortest. Before you remove the stick from the ground, carefully measure the length of that part of the stick above ground. This procedure should be exactly repeated at the other site.



**How shadow length and gnomon height determine the altitude A of the Sun**

Convert your measurements of the shadow’s shortest length and the gnomon’s height to an altitude of the Sun at local noon as follows. First, compute the ratio

length of stick

length of shadow

for your two observation points. Next, use your calculator to compute the arc tangent (inv tan or tan1) of the ratio. Your result is the elevation of the Sun. If the Sun has changed position in the sky significantly between your observations, you will have to correct for this by determining the declination of the Sun on these two dates. Ask your instructor for help with this. If you observe on consecutive days, this shouldn’t be a big problem.

Measure the difference between the two elevations you measured... this is how much higher (or lower) the Sun is in the sky at your new location. If you know the distance you travelled North or South, then you can set up a proportionality: The distance you travelled over the Earth’s circumference is the same as the angular difference over 360 degrees. Since you know everything except for the circumference, you can solve for that and get your answer for the questions below.

Questions:

(1) Show your work in setting up the proportionality and solving for the Earth’s circumference. Watch your significant digits!

(2) List at least five sources of error in this experiment, including numerical estimates of each and how these estimates affect your answer to (1). Also, state how each error could be reduced or eliminated.

(3) To find the total estimated uncertainty in your experiment, it is not quite correct just to add up the individual errors. You must square each of the errors you calculated in part (2), add the squares, and take the square root of the sum. (Ask for help if this instruction isn’t clear.)

(4) State the actual value for the circumference of the Earth. Does your value plus or minus the estimated uncertainty match the actual value?

(5) You may have noticed that the noon shadow was shorter depending upon how far South you were for each of your measurements. How far South would you have to go on June 21 (the summer solstice) in order to make the noon shadow completely disappear? Explain your answer with a diagram.

(6) How could you prove that this effect is really due to the curvature of the Earth rather than the Sun just being a short distance away from a flat Earth? (This is not easy!)

Be sure to follow the format described in the introduction in writing up your results.

**Skylab #3**

**“Where did I put that chart?!”**

Introduction: Contrary to popular opinion, the sun does not always rise and set at the same spot on the horizon, and there are in fact only two days each year when it rises exactly in the East and sets exactly in the West. For this Skylab, you will establish these facts for yourself. This lab gives you a great excuse to actually go out and watch some beautiful sunrises and sunsets.

Equipment: Your eyes, a compass, a watch and a camera or sketch pad.

Time Required: A few minutes on as many evenings and/or mornings as possible during the quarter. The sooner you start, the more data you’ll have.



**Always stand in the same spot to make this measurement.**

What to Do: Choose a convenient spot with a reasonably clear horizon. On as many evenings/mornings as possible (at least 10, but 15 is preferable), observe the sunsets/sunrises from the same spot and, with the aid of landmarks on the horizon (mountains whose compass positions must be measured at one time), record the precise position (as well as you can determine it) and time at which the sun sets or rises. Weather may be a problem (especially in the morning), but you will find that you can probably see the sun even through moderately thick clouds.

Make a chart on which all the positions are plotted; each point should be labelled with the data, time of sunset/sunrise, and azimuth (defined as the angle along the horizon from north: North = 0 degrees, East = 90 degrees, South = 180 degrees and West = 270 degrees. A simple chart with the sun’s position marked on each date, as well as time of sunset is sufficient. You may show your observations on the sketch that you make of the horizons, or using a telephoto shot of a sunset.

Remember that compass needles point to magnetic north, which is approximately 7 degrees west of geographic north in the Westerville area.

Questions:

(1) At what date during your observations was the sun furthest north on the horizon? Does this coincide with the latest sunset/earliest sunrise? Explain why we expect it to coincide (a diagram would be helpful).

(2) List at least four sources of error in this experiment. With each, state the approximate size of each error and how it might be reduced or eliminated.

(3) You probably noticed that the sky is always red in the direction of the sunset or sunrise. Why does this happen? Hint: This also explains why the sky is blue.

Be sure to follow the format described in the introduction in writing up your results.

**Skylab #4**

**“That thing is supposed to be a bear?!”**

Introduction: Many Astronomy students wish to learn the constellations. Here is your opportunity both to learn and get credit for a skylab. You will also see how stars move through the sky on paths that may surprise you.

Equipment: See Skylab #1 for list. Plus you’ll need a simple homemade quadrant (see below for an example).

Time Required: One entire, clear night.



**A homemade quadrant. The thread indicates the angle of the object from the horizon.**

What to Do: On a clear dark night, preferably away from city lights (if the weather cooperates, pick a night near New Moon), begin by finding the North star, Polaris. Look in the northern half of the sky about 40 degrees above the horizon.

Polaris is located at the end of the handle of the Little Dipper (part of Ursa Minor).

Use your home-made quadrant to measure its altitude above the horizon. Now use your star chart to pick out at least four constellations and memorize what they look like. Pick on prominent star in each constellation and measure its altitude above the horizon. You may need a friend’s assistance to do both sighting and reading simultaneously.

Repeat this process every hour or so, recording the time and elevations of the stars. Mark on your star chart your rough estimate of how each star moved over the past hour relative to its initial orientation.

Between measurements, try learning a few more constellations. The final step (the next day, after sleeping) is to prepare a graph showing the elevations at each hour through the night.

Questions:

(1) Why do some stars change elevation more than others? Give two reasons and use a diagram if that would help make it easier to explain.

(2) How do all the stars move relative to Polaris (the north star)? Up? Down? Clockwise? Sketch it or show it on your star chart.

(3) Do all the stars move from East to West? Use your chart to explain your answer.

(4) What causes a star to twinkle? Does the amount of twinkling a star does change through the night? What factors would contribute to any change in twinkling (give at least two)?

Be sure to follow the format described in the introduction in writing up your results.

**Skylab #5**

**“Take a Photo!”**

Introduction: This lab involves taking long exposure photographs of the night sky. The stars appear to rotate once around the Earth in a day, but it really is the Earth that is rotating. In this lab you should measure the duration of one rotation, this is the duration of a sidereal day which is slightly shorter than 24 hours.

Equipment: You need a camera which is capable of making long exposure photos, i.e. the shutter period has to be manually adjustable. You also need a tripod to mount the camera absolutely stable.

Time required: About an hour for a couple of nights which do not have to be adjacent.

What to do: At a couple of clear nights far away from the city’s light pollution take photos of the night sky centered around the north pole star, Polaris. Polaris does not have to be at the center of the photo, but should be in the photo. Long exposure time is crucial.

The stars will establish part of an arc around Polaris on the photo. We want to measure

the angle that they are making during the exposure time and then calculate how long it will take them to make a complete rotation of 360 degrees.

As an example, if you have an exposure time of 10 minutes the stars will travel about 2.5 degrees around Polaris, which will be pretty hard to measure exactly. Try to go to longer

exposure times and make as many photos as you can to get as many measurements to bring down the statistical error. Also measure the angle of as many stars in a photo as you

can. The measurement of the angle is, of course, from Polaris, so you have to be able to identify Polaris in the photo.

Questions:

1. Make a chart of the angles measured versus the exposure time.
2. Calculate the length of the sidereal day by using the following proportionality: , and solve for the length of the sidereal day. The units will be the same units you used for the exposure time. The proportionality is clear: the exposure time is as big as a fraction of the sidereal day, as the angle by which the stars moved during that time is as a fraction of the full 360 degrees of a complete rotation. Do a cross-check: is the value for the length of the day in the vicinity of 24 hours (=1440 minutes)? If not, something went wrong; hopefully the calculation.
3. Calculate the statistical error of the measurement (ask me about details of error calculation)
4. Which other sources of errors can you think of? Make a list of these systematic errors and estimate their impact on the result. If you are in a group, discrepancies between group members as to what the angles are might help you estimate your uncertainties.
5. Compare the value you obtained to the actual value in the literature. Is your value close?
6. Why is the sidereal day shorter than the solar day? What are the consequences? Why is the human calendar based on the solar day?

Be sure to follow the format described in the introduction in writing up your results.

**Skylab #6**

**Simulated Experiments**

In case the weather does not cooperate, or if you just find them more interesting, two simulated experiments are available. In one, you study the motion of the moons of Jupiter and use Kepler’s 3rd Law to determine Jupiter’s mass. In the other you verify Hubble’s Law by measuring the distance and recession velocity of distant galaxies; the value for Hubble’s constant you obtain then gives you a measurement of the age of the universe. These were developed by Project CLEA at Gettysburg College.

For each of these you will need to download and install the simulation program, available at the course web site. You should also obtain the corresponding student manual, which contains background information and instructions for completing the lab. There is also a data sheet and a list of questions you should answer; this is what you hand in for the Skylab. **You must also hand in any raw data files for your work, either printed hard copy or by email.**

Once you have downloaded the simulation (.EXE file), double-click on it to install the software. Consult the manual for operating instructions. It will step you through the measurements and any calculations and analysis. You may need to refer to the text for additional background and details. Note that Hubble’s Law will not be covered in class until week 8, so unless you read ahead you may need to wait until then to get started on this one.

Remember: for the simulated experiments you hand in the worksheet(s) with your results and analysis, answers to any questions in the manual, and your raw data files. **You do not need to write a separate report for these Skylabs.** Please come ask me if you have any questions as you work on these projects.

1. Make sure it is a fixed star and not a planet, as planets move with respect to the celestial sphere! [↑](#footnote-ref-1)