Astronomy 101U Skylab #0 – Introduction

Included in this handout are seven at-home labs, one of which you must do at some point during the quarter. I name them Skylabs so that they're easy to refer to, not because I think you're going to crash and burn on them! Later in the quarter, we will discuss more possible labs if you can't find one of these seven that interests you.

I. Recording data

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

II. Displaying your results

When a scientist communicates results to colleagues, he or she wants to display data in a manner which makes it as easy as possible for the reader to understand. The data will usually be arranged in a table or in a graph. It is important that in your Skylab write- up you present your data in a clear manner; see page 4 for an example. Besides a neat "final" display, you must also submit your original notes, sketches, etc., as taken in the field.

III. Errors (this is long, but believe me, it's important!)

In every measurement we make, there is an unavoidable error, regardless of the quality of equipment or observing skill. It is important for a scientist to make a good estimate of these errors. The conclusions you reach in your experiment are only as good as your estimate of the error involved. Having very small errors relative to your experimental values is not necessarily a measure of how well you did the lab (although you should try to minimize errors as much as possible).

Much more important is the concept of scientific integrity, as discussed at length in the Feynman article "Cargo Cult Science." Unless you give the reader an honest attempt to explain everything that could possibly have gone wrong with your experiment, you're not doing science. You may be able to say that the length of the sidereal day is 23 hours and 52 minutes plus or minus 30 seconds, according to your most precise measurements, but if you look back carefully on your procedure, you may find that you used different reference points from night to night. Failure to take this into account has made your error bars artificially small; hence, your results are almost completely worthless!

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, artifically dimming the objects. If we don't take this possibility into account as part of our data reduction, we 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 above example, we avoid this problem by observing "standard" stars every night to calibrate the brightnesses 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 we measure the number of steps it takes us to walk across campus, we might get 500 one day and 520 the next, then 493 the next, so we would take the average of all of these and estimate 20 steps to be our random error. In this case, random errors could be caused by the direction of wind blowing on the particular day, how tired to walker is, etc. A systematic error might be deciding to walk a different way around a certain building after the first few trips or buying a new pair of shoes halfway through the series of trial runs and wearing them the rest of the time.

If we were to perform more than just 3 trial runs...say, 300, we would get a much better idea for the estimated random error, hence, our results would be much more reliable! The concept of averaging many measurements of a quantity to obtain a more accurate description of that quantity is very important. If the errors in the measurements are truly random, they should just about cancel each other out in the averaging process. Of course, the more measurements we include in the average, the better the errors will cancel each other. We should thus repeat our measurements as many times as is reasonable and average all those measurements to arrive at a "best estimate" of the quantity sought (since we have minimized random errors..of course, this assumes we have managed to eliminate systematic errors!).

Remember, error is not something magical which no scientific laws govern. Also, the values you often see quoted in textbooks ("book values") are not written there with a finger of fire by some sort of Divine Being. 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 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! Paying careful attention to little discrepancies and reducing the error bars sufficiently to discern them are primary qualities of a Nobel prize winner.

Why should you have to worry about errors so much? Because it is a crucial part of science! It's not good enough to just write down your measurements; people need to know how much faith to put in your results. Say you are measuring the resonant frequency of the wings of a DC-10. 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.

To give a more down-to-earth example, in the world of astronomy, theoreticians will give up their pet theories if and 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 experimentalist, especially if he/she spent thousands of dollars and months of his/her life working on it. You see, no one is interested in your measurement per se; what they're interested in is 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. Your measurement might be very close to the true value, but how would you know? Error analysis tells you how much you can believe in your measurements.

We've already given a few examples which tell us how to cope with errors, but here the method is repeated clearly:

(1) Find all the sources of error.
(2) Estimate the sizes of the errors.
(3) Try to reduce their sizes as much as possible.

Finding the sources of error is not as easy as one might think. The weirdest things can cause errors through a long chain of intermediate processes. For example, Eotvos did historic experiments in 1922 in which he showed that the inertial and gravitational masses were the same to one part in a billion. Sixty-three years later, people reanalyzed his data and extracted a statistical correlation which indicated (to them) the existence of a fifth force. What they neglected to consider was the influence of Eotvovs' own weight, which interacted with the apparatus directly (through gravity) and indirectly (through the floor, which deformed slightly due to his weight)! When doing error analysis completely, you must consider <u>everything</u>!

Granted, that's a lot to ask, but I'll help you along during the quarter with this concept, and I'll help you come up with some of the possibilities, both in your skylabs and in your homeworks and in-class labs. The way to think about this is to define for yourself exactly the situation that you imagine would produce a perfect, errorless measurement. List all the things which participate in the experiment, then define their perfect situation exactly. That means to state:

1. Where they are;
2. How they are moving;
3. What they are made of;
4. What shape they have;
5. What their internal state is;
6. How they are situated relative to each other;
7. What they are doing;
8. What is being done to them;
9. How all these things are coordinated in time.

This checklist comes from Aristotle himself! If you don't believe me, read his books Categories and Physics. By explicitly stating all the variables that need to be defined to define the perfect, errorless measurement, you have all the variables in which you could get some error. Then you need only go through the list, and for each variable

1. Check if you get error;
2. If so, from what sourse, and then
3. Quantify (or estimate) the error.

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 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 read 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 snowback, is only as good as its weakest link.

V. Working with others

Many students like to work in groups while carrying out their skylab 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?). I have no objections to this so long as each person contributes to the observations in a significant fashion and each person separately writes up his or her own report (i.e. the collaboration should end as soon as all of the data is taken). In such a report, you should mention the names of your collaborators and state who did what.

Sample Skylab Write-Up
(to give you a general idea)

Name: Al D. Baran

Lab #3 - The Gnomon

Objectives: To determine the motion of the Sun across the sky in a day's time.

Date and Place of Observations: July 11, 1993; Seattle (Green Lake park)

Procedure: Outline exactly how you proceeded with your observations, especially if different from the write-ups.

Data:

Time (PDT)	Angle	Shadow Length	Comments
8:05 AM	151	55.6 cm	
9:00	142	47.8	
10:10	130	35.2	
11:10	-	-	Sun covered by clouds
11:40	115	25.3	Sun's first appearance since 10:30
...			(more data)
1:10 PM	86	21.7	Stick knocked over; set back as
1:30	81	22.9	straight as possible
...			(more data)
7:35	12	67.7	Sunset

(A well-labeled scale drawing showing the path that the tip of the shadow took would be a good idea here as well. Your raw data and notes should also be turned in.)

Questions: Here you answer any questions asked in the lab itself.

Discussion: 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 should 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.