Astronomy 1 – Introductory Astronomy
Spring 2014

Lab 2: Observing the Sky pt. 1

Quick overview

Meet at 8 p.m. in Science Center Room 187. We will meet no matter what the weather.

Dress warmly! It can be incredibly cold standing still under the stars in the winter. Wear considerably more than you needed during the afternoon. Unless it's well above freezing, a heavy coat, gloves, a hood or hat, and a scarf are a minimum.

Before coming to lab

Read "The Local Sky" on p. 29 of the textbook and study Fig. 2.6 carefully. And also read "The Celestial Sphere" on p. 28 and study Fig. 2.4. And read pages 88 and 89.

Introduction

Part I: The Changing Sky

Most people know that the Sun, Moon, and stars appear to move through the sky over the course of a 24-hour day as the Earth turns on its axis. However, careful observation shows that Earth's rotation is not enough to account for all the movements in the celestial sphere. In particular, we can see that the Moon is not in the same position (or the same shape!) at a given time night after night. In fact, there are times when the Moon is visible in the daytime. If we note the position of constellations over the course of a month or so, we can see that they also appear in different locations at the same time of night.

The main goal of tonight's lab is to become acquainted with some of the major constellations and with some of the tools of astronomy. You will also make some careful observations of stellar positions to compare with observations you will make later in the semester. We will begin with a few indoor exercises that should help you understand why we see seasonal changes in the night sky. As you do these, remember that you will be observing the sky later tonight but also later in the semester and so you will get to see how the constellations' positions change over the course of about two months (but viewed at the same time of night).

The Ecliptic and Zodiac Constellations

The ecliptic is a path the Sun appears to travel with respect to the stars over the course of the year. (The Moon and planets also appear to move through the sky on or near the ecliptic, as well.) In antiquity, astronomers noticed that the Sun "passed through" the same constellations year after year. In Greek and Roman astrology, these constellations became known as the zodiac, since most of the patterns represented animals, real or mythical. We can begin to think about why we see different constellations at different times of the year by looking first at which zodiacal constellations we can see.

On the floor at the center of the room are the months placed in a circle around the "Sun". This circle represents the Earth's orbit, and the position of the Earth through the year. Each student should choose a month to stand on. The zodiac constellations are taped on the walls to represent the ecliptic.

Your lab instructor will guide you through the following observations, so you can record your observations in your notebook.

Note: whatever direction your eyes are facing, that's the meridian (or due south).

Q1. Record the month on which you are standing. What constellation is up at midnight? In front of which constellation is the Sun?

Everyone move three months forward in time.

Q2. Repeat question 1 for your new position.

Q3. When it is midnight now, where (east, west, etc.) is the constellation that was up at midnight in Q1?

Move ahead three months more.

Q4. Same observations. How do these two constellations relate to those you noted in Q1?

Q5. (Answer this anytime before you leave tonight.) In your own words, and with a diagram if you like, explain why we see different constellations in the winter than we do in the summer.

Solar and Sidereal Day

In the previous activity, we could easily see that the zodiac constellation visible at midnight changes from month to month. If we make careful measurements, we can even see that the stars on the meridian at midnight change slightly night to night. This indicates that there is a difference in the length of a solar day and a sidereal day (literally, a "star day").

Once again, you will play the role of "Earth". Stand at a point in the orbit and face the "Sun". One solar day is the time it takes the sun to make a complete cycle through the sky. The easiest way to measure this is from one noon to the next (i.e. from one meridian crossing to the next). Stand in place and turn counterclockwise to simulate one day.

Of course, the Earth constantly moves along its orbit about the Sun while also turning on its axis. This time make take one step counterclockwise around the orbit while turning. Note where a star – or spot on the wall – that's behind the Sun when you start ends up when you're back facing the Sun again.

Q6. How much did you have to turn in the first case (a full turn, a little more, a little less)? How much did you have to turn in the second case to return to "noon"?

Hopefully, you can see from this demonstration that Earth must rotate slightly more that 360^o for one solar day. If we measure the length of the day based on the time for a star to travel back to the meridian, Earth only needs to turn 360^o, so a sidereal day is a little bit shorter than a solar day.

Q7. If Betelgeuse, one of the stars in the constellation of Orion is on the meridian at 9:00 PM on February 3, at 9:00 PM February 4 it will be
a) slightly East of the meridian
b) on the meridian
c) slightly West of the meridian

Synodic and Sidereal Month

The Moon's orbital period is 27 1/3 days. This is called a "sidereal month", since it is the time for the Moon to return to the same position with respect to the stars. The period for the full cycle of Moon phases is 29 ½ days. This "moonth" is measured from new moon to new moon. Since new moons occur when the Moon and the Sun are on the same side of the Earth, one can think of the Moon and Sun as "meeting". The Latin word for "meeting" is "*synod*". Hence, the 29 ½ day period is a synodic month.

Why is the synodic month a little longer that the sidereal month? We can use our simulated orbit one more time to help us understand. Take a Styrofoam ball to represent the Moon. Your head will be the Earth. While standing in place and facing the "Sun", have your "Moon" make a full cycle from new Moon to new Moon around your head. Next, have the Moon go through its full cycle while you move to the next month position.

Q8. Describe what you observe in the two cases.

While you have the Styrofoam balls playing the role of the Moon, turn on the light bulb at the Sun's position and see how you can reproduce various moon phases.

Part II: Measuring Angular Positions

Note: Much of this information about angles should be review.

When we make measurements of distances on the ground, we use units of length like inches, centimeters, or miles. However, we cannot use such measurements to describe the positions at which objects appear in the sky. For example, how far is it in the sky from a star on the horizon to one directly overhead? Three feet? Two miles? Because we have no depth perception when looking objects so far away in the sky, these measurements simply don't work. Instead, we use angles. Then, we can easily say that it is 90° between the two stars.

The unit of angle that you are probably most familiar with is the degree, with the distance all the way around a circle equaling 360°. To give you an idea of how big this is, the angular diameter of the full moon, as observed from Earth, (its size *as an angle*, not in miles or kilometers) is about 0.5°. You can see even from this simple example that astronomers deal with angles smaller than one degree; indeed, using large telescopes allows us to measure angles thousands of times smaller than a degree. Thus, it is useful to have other units of angles with which to work. The most common are the *arcminute* and the *arcsecond*, where

$$1° = 60 \text{ arcminutes} = 60'$$
$$1' \text{ (arcminute)} = 60 \text{ arcseconds} = 60''$$

You can see that arcminutes are often abbreviated with a single quote (') and arcseconds with a double quote ("). They are also often abbreviated *arcsec* and *arcmin*. In this lab we will use only degrees.

When you want to measure lengths or distances on the ground, you use a ruler or tape measure. Similarly, in order to measure angles on the sky, you need a measuring device. In the lab we have several plywood arcs for this purpose. Each is exactly one quarter of a circle, as if we had a large plywood pizza and then sliced it evenly into four pieces. The angle around a whole circle is 360°, so a quarter of a circle makes an angle of 360°/4 = 90°. You can also visualize how the cuts required to divide a pizza into 4 pieces would meet in the center at right angles to one another.

Each of our plywood arcs has angle marks along the curved edge, going from 0° to 90°, with larger, labeled marks every 5° or 10°. To use it, hold it up to your eye so that your eye is where the center of the pizza would have been (note that the sharp corners at this point have been removed to make space for your eye and to make this procedure safe!). To measure the angle between two objects, align the plywood arc so that the straight edge marked with 0° is pointed at one of the objects, and the other is almost hidden behind the curved edge with the angle marks. Keeping the 0° straight edge lined up with the first object, move a finger along the curved edge until your finger exactly lines up with the other edge. Grip the plywood with your finger at this point and lower it from your eye. You can then read off the angle mark where your finger is: this is the angle between the two objects.

It has probably occurred to you that this will only work if the objects are less than 90° apart – otherwise you would need a larger plywood arc, say half a circle rather than only a quarter of one. You will not need to measure angles larger than 90° in this lab, except along the horizon when you are measuring the azimuth of a star. In this case you can sight along the 0° straight edge to one object, and then look to see where the 90° straight edge is pointing. Remember that place, move the plywood arc over so the 0° straight edge is pointing where the 90° straight edge was before, and then use your finger to mark the position of the second object exactly as before. Add 90° to this measurement to get the true angle. You can even measure angles greater than 180° by moving the plywood arc over twice and adding 180° to your final answer.

Measuring altitudes, angular distances above the horizon, is easy. Objects with an altitude of 0° are on the horizon while objects with an altitude of 90° are directly overhead (the **zenith**). Just hold the plywood arc vertically, sight the 0° edge at the horizon right below the object, move your finger along the curved edge until it lines up with the object, take the arc away from your eye and read off the altitude.

Before leaving the lab room, practice your angle measuring technique by measuring an object of a known size at a known distance. In this case, there is a mark on a wall and a line marked on the floor at a certain distance from it. For example, if you stand 20 feet away from a mark on the wall which is 1.75 feet (21 inches) long, then the angular size of that mark will be 5°.[1] Stand at the indicated distance from the wall, and use your plywood arc to measure the line. The marks should have an angular size of 5°. Practice using the arc until you measure the tape strip accurately.

The lab continues on the observing deck.

Determining Latitude

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[1]Any distances can be used; as long as the distance from the object is 11.43 times the size of the object, then the object will appear to be 5° in angular size.

You will use one of the plywood arcs to determine your latitude on the Earth using a technique that has been used for navigation for thousands of years. Go outside, locate Polaris (the North Star), and measure the *altitude* of Polaris. The altitude of a star is the angular distance between the star and the point on the horizon directly below the star. Objects on the horizon have an altitude of 0°; objects directly overhead have an altitude of 90°. Measure the altitude several times, as carefully as you can. Try to record what the arc actually reads each time as exactly as you can (rather than, say, rounding it off to the nearest 5°). Take an average of your measurements and use this as your best value for altitude.

Q9. What is the altitude of Polaris? By how much did your repeated measurements vary? List *all* of your measurements here, and also quote the average and the range (which gives a sense of the variation due to measurement error).

To determine the latitude of Swarthmore, use this simple rule:

The altitude of Polaris = your latitude

Q10. What is the latitude of Swarthmore?

Recall that latitude runs from 0° at the Earth's equator to 90° North at the Earth's north pole. Also recall that Polaris is roughly directly above the Earth's north pole.

To understand *why* the altitude of Polaris equals the latitude of the observer, consider the picture below, and imagine what it would look like for observers at different latitudes. Because Polaris is so far away, the direction to Polaris from any observer on such a diagram will always be directly toward the top of the page.

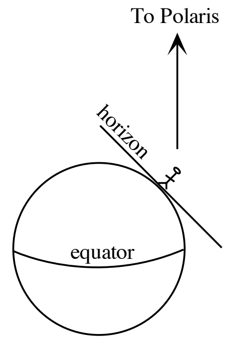

Figure 2. The relationship between latitude and Polaris' altitude for an observer in the Northern hemisphere. Note that Polaris is so far away from Earth that in any drawing like this, the direction to Polaris will always be directly toward the top of the page, not at an angle.

Sometimes when you make a measurement, there *is* a more accurate measurement available to which you can compare your answer. If this is so (and often it is not), then you can compute the **percentage error** of your answer:

$$\text{Percentage error} = 100 \times \frac{|\text{ Your answer} - \text{right answer }|}{\text{right answer}}$$

The vertical bars on the top of the fraction mean that you should take the absolute value of the difference, so that percentage error is always a positive number.

Q11. Given that Swarthmore's latitude is 40° North, calculate the percentage error of your answer. Show your work. (This calculation can be done inside!)

Finding your way around the sky

In this part of the lab, we'll learn some of the basics of where things are in the sky, and then make some measurements of their positions.

When you first start to learn the sky, the number of different constellations can be a bit overwhelming. One good way to get started is to learn to recognize one constellation that is fairly bright and easy to find. Then you can learn the positions of other constellations and stars relative to your “landmark” (skymark?) and you will be able to find them later, even if everything has moved.

In the winter sky, Orion is a good starting place. You may already know this constellation; if not, one of its most prominent features is the “belt” of Orion, three stars of roughly equal brightness evenly spaced in a straight line. If you do this lab early in the evening in the winter, look for Orion about half way between the horizon and the zenith in the southeast.

Another way to help you get oriented is to use a star map. The star maps distributed with this lab are accurate for our latitude (roughly 40° North) and for roughly 9:00 PM if used in the middle of the month. The map shows the whole sky, with the edges corresponding to the horizon in different directions and the middle corresponding to the point directly overhead. If you face north and hold your star map up in front of you with the part of the horizon marked “North” at the bottom, the lower part of the map should match what you see in the sky. For the southern sky, turn around to face south, and turn your star map over so that you are looking at the side marked “South”. Again, the star map should match what you see in the sky. Remember, the middle of the map is straight up; note that this is roughly where the bright star Capella is on the map, so look up and see if you can find it. You might start with Orion, then go up above Orion’s head to the next bright star, which is Capella.

Q12. Find all of the six stars in the “Winter Hexagon” shown on your star map (Capella, Aldebaran, Rigel, Sirius, Procyon, and Pollux). How many stars in all of the rest of the sky are brighter than any of these stars? List the names of any brighter stars you find, as well as those of any that are close to the brightness of the Winter Hexagon stars.

One goal of our observation labs is to see the changes in the night sky over the course of the semester. We can try to quantify this by carefully measuring the angular position of one star. We can uniquely express the location of an object in the sky with two measurements: the **altitude** and the **azimuth**. As with your measurement of Polaris, the altitude is measured straight up from the horizon. The azimuth is measured along the horizon, with 0° corresponding to due North, 90° to East, and so on.

Q13. Measure the altitude and azimuth of Betelgeuse, the bright star in the shoulder of Orion. As with the altitude of Polaris, measure each quantity several times, being careful to record each result as carefully as possible. Then you can average your measurements together to get your final answer. Also record the time at which you make these measurements.

Finding the constellations

Now that you have a start finding your way around the sky, locate some of the major constellations. In your notebook, make a table like the checklist given below. Check off each constellation as you find it, and jot down any notes that may help you remember how to find it or recognize it next time.

Constellation checklist (This table ***is*** part of the write-up; it can be cut out and taped into your notebook)

Name	*Found?*	*Note to yourself*
Orion		
Auriga (The constellation of Capella)		
Taurus (The constellation of Aldebaran)		
Gemini (The constellation of Castor and Pollux)		
Canis Major (The constellation of Sirius)		
Canis Minor (The constellation of Procyon; only two stars easily visible)		
Orion (The constellation of Betelgeuse and Rigel)		
Ursa Major/Big Dipper (It will just be rising)		
Ursa Minor/Little Dipper (Only 3 stars easily visible)		
Cassiopeia (May be getting low in the northwest)		

Colors of the stars

Though you may not notice it with a casual glance at the sky, different stars have different colors. Look around the sky at the brightest stars and see if you notice any color differences.

Q14. Find Orion and compare the colors of Betelgeuse and Rigel, the two brightest stars in Orion. Describe the color of each star. (They may look the same at a casual glance, but they are not! Take your time and look carefully for subtle differences.) Describe the colors of the two stars. What does the color of these stars tell you?

Sketching the sky

As the semester progresses, the appearance of the sky will change. In order to record these changes, you will be asked to sketch the appearance of the northern sky and the southern sky twice during the semester, beginning tonight. Using a full notebook page for each, *carefully* sketch the appearance of the sky while facing north and while facing south. Use as much of the paper as possible, and sketch in some landmarks along the horizon. Take your time; you will be graded on the neatness and carefulness of your sketch. It is in your best interest to be as careful and methodical as possible since this will help with the other observations. To help keep your sketch at the proper scale, be sure to identify some constellations as you sketch. For any constellations you include, connect the stars in them and label each constellation on your sketch. Similarly, label any bright stars for which you know the names. Although you should use the map to identify constellations, be sure to draw *what you actually see in the sky* rather than copying your star map.

Q15. Northern sky sketch: Center your sketch on Polaris, the North Star. Include the Big Dipper, the Little Dipper (as much of it as you can see), and Cassiopeia (again, as much of it as you can see). Also draw the water tower as a reference marker, along with any other horizon features you think will be helpful. Be sure to include the time, location, date, and sky conditions (e.g. clear, partly cloudy)!

Q16. Southern sky sketch: Make your sketch facing directly south. (You may wish to turn your notebook to draw in "landscape" mode.) How can you tell if you're facing due south? Where will Polaris be when that's true? Draw a straight line down the center of the page to represent the meridian. Include at least one feature on the horizon (like the Clothier bell tower) as a reference point. Draw the constellations on or near the meridian. Again, be sure to include the time, location, date, and sky conditions.

Telescope Observations

To conclude the evening's observations, work with a partner and use a telescope to find as many of the objects in the table below as possible. As part of your lab write-up, indicate which objects you could see and a description. (Putting this in tabular form is a good idea.) Pointing the telescope is easy! Use the handset and follow the telescope command instructions in the table below to have the telescope move to the object. Once the 'scope beeps to indicate it has arrived, you will probably need to center the object in the eyepiece. (Hopefully, the telescope is well enough aligned that the object is somewhere in the field of view!) Use the arrow buttons on the keypad to make fine adjustments. You can adjust the speed at which the 'scope moves by hitting the "Speed" button and then a number from 1 to 9. (A rate of 4 or 5 is probably pretty good.) Because the telescope optics flip the image you see, the arrows may not move the telescope in the direction you think they should.

Object	Description	Telescope Command
Jupiter	Planet. Look for variations in color. (May see lighter areas around the poles.)	"SS"; use up/down buttons at bottom of keypad to scroll to name. "Enter"; "Goto"
Moon	Pan around to see different	"SS"; use up/down buttons at bottom of

	parts of the Moon.	keypad to scroll to name. Press "Enter" twice; "Goto"
M42	Orion Nebula	"M"; type number; "Enter"; "Goto"
NGC 869 / NGC 884	Double open cluster; rich field of stars in Perseus	"NGC"; type number; "Enter"; "Goto"

Guidelines for your write-up

This lab has many different parts, and is focused around the numbered questions (some of which include things like tables and sketches, which will go into your lab notebooks, too). So for this lab, just:

- Title, date, lab partner
- Purpose statement describing the goal of the lab (does not have to list each separate activity; just give an overview).
- Answers to numbered questions
- A concluding section, which can be just a paragraph and should restate your main results and particularly your quantitative results.