

Laboratory Manual for Astronomy

Astronomy 212

Fall 2009

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Introduction

Archeology has shown an ancient human interest in the sky. Generally it is assumed that this interest was based on practical concerns: scheduling plantings and meetings. It's also true that the night sky is an awe inspiring ballet, although the pace of the show is rather slow by modern standards. I imagine the slowly evolving show was filled with stories¹.

In recorded history we find the sky used as a billboard for the gods. You can hear an echo of those advertisements in our day-names: Sun-day, Moon-day, Tyr's day (the Nordic god Tyr—the approximate equivalent of the Roman god Mars; note Latin: Martis dies), Wodan's day, (Latin: dies Mercurii reflects the Roman god Mercury), Thor's day (this god of thunder is reflected in German Donnerstag; Jupiter/Jove was the Roman god of thunder hence Latin: Iovis dies), in Latin Friday is dies Veneris, “day of Venus”, and Saturn-day. Seven days for the seven ‘planets’.

Today notice is rarely taken of the sky's endless movements, and in big cities we blot out the sky with street lights. The purpose of these labs is in part to get you in touch with the night sky and, hopefully, to generate some of the awe that the ancients felt for the heavens above them. Additionally the firm foundation of science is observations; Measuring is not the same as understanding, but it is a good start. Most of the observations you will make this semester will be similar to those that have been made by countless astronomers throughout history. However, they will likely be new to you, and give you the opportunity to discover the nature of the universe for yourself.

Plagiarism

It is a lie to present the work of others as your own work. Working these projects with your classmates is helpful, but every observation recorded here should have been witnessed by your eyes; every sketch recorded here should be drawn by your hand—and not simply traced from a friend's work. I will be particularly suspicious of identical sketches and numbers.

¹Donkey: Hey, can you tell my future from these stars?
Shrek: The stars don't tell the future, Donkey. They tell stories. . .
Donkey: That ain't nothin' but a bunch of little dots.
Shrek: You know, Donkey, sometimes things are more than they appear.

Home Lab 1: Moon Motions

Apology: This lab has a lot of ‘instructions’ and ‘rules’; the pejorative term for labs like this is ‘cookbook’. In my real life as an astronomer, I have little use for ‘instructions’ and ‘rules’; new discoveries rarely result from repeating an old recipe. So given that this experience is nothing like research, why foist it on you?

You can observe a lot by just watching.

—Yogi Berra (1925–)

I’ve found that, looking through the eyepiece, beginning students often miss much of what is actually visible. It seems to take practice (and often prompting) to take notice of all that can be seen. Drawing seems to be a good way of forcing you to take in the details. (And it provides me with hardcopy to assess your ability to take cognizance of what actually *is*.)

Additionally while following a recipe does not make you a chef, I bet most chefs started by following recipes. A lot of science (and cooking) involves rearranging or re-purposing recipes other folks developed.

Purpose

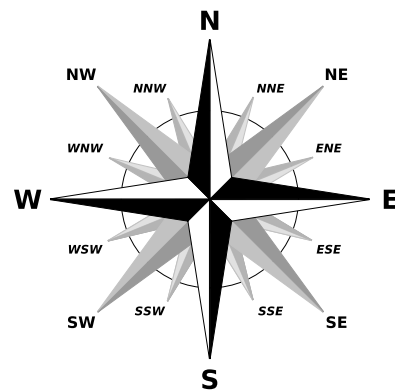
The aim of this project is to observe the cycle of Moon phases and interpret the results in terms of the orbit of the Moon around the Earth. Lecture and the textbook should have explained the basics of the Lunar cycle but you will now be responsible for observing and recording exactly how this cycle plays out in our Minnesota skies. It *should* be easy to reproduce on paper the scene in front of you, but—if the future is like the past—many of you will let your pre-conceptions trump the reality before your eyes!

Rules

You are to make a total of nine observations of the Moon on seven distinct, non-adjacent days; the results are to be recorded in seven drawings in the provided drawing blanks. (The first drawing will be a superposition of three observations made a few hours apart.) I’ve included an 8th drawing blank that you can use as needed. Each observation should include:

1. LOCATION: Where were you when you observed the sky?

2. DATE: Record this in the form yyyy/mm/dd where yyyy will be 2009, mm will be exactly two digits for the month and dd will be exactly two digits for the day. (e.g., 4th of July = 2009/07/04).
3. TIME: Record this in Central Standard Time on a 24 hour clock basis. Most of your observations should be completed before the November 1 ‘fall back’ date, so you will usually subtract one hour from the Central Daylight Time on your watch. Time should be expressed in the form hh:mm. (Again: no A.M. or P.M.: afternoon times simply have 12 hours added, so 1 P.M.=13:00). This time should report the time at the midpoint of your observations.
4. ALTITUDE: Using the “handy protractor”² record the number/fraction of hand-spans, fists, etc., between the Moon and the mathematical horizon and then convert that to degrees. Round your degree conversion to the nearest $\frac{1}{2}^\circ$.
5. AZIMUTH: Start with the cardinal directions: NESW. Midway between north and east is NE. Midway between NE and east is ENE. The resulting 16 directions are displayed in the ‘wind rose’ to the right. Note that both SJU and CSB buildings are generally constructed nearly along the cardinal directions. At night you can use Polaris to find true north, or use a GPS or compass. The Moon’s azimuth should be recorded as one of these 16 direction indicators perhaps further subdivided using hand-spans, fists, or pinkies (converted to degrees). Write this azimuth indication at the corresponding point at the bottom of the drawing (which represents the mathematical horizon).
6. PHASE: Record one of the following terms: waxing crescent, first quarter, waxing gibbous, full, waning gibbous, third quarter, waning crescent, new. The underlined terms (which actually occur at an instant of time just like ‘noon’ does) can be modified to indicate a bit before or after the precisely defined instant. Additionally report your estimate for the fraction of the Moon’s observable disk that is illuminated (e.g., the quarter phases would be 50%).
7. CONSTELLATION: If bright stars are visible when you observe the Moon, bring your *Star & Planet Locator* with you when you observe. Set the date/time on the Locator, and by matching the actual sky with that shown by the Locator, determine where the Moon would be on the Locator’s sky map. Record the constellation that seems to include the Moon. (Use the number in the *The Ecliptic & Constellations of the Zodiac* Table on the back of the Locator. If your observed constellation does not seem to match any numbered constellation, select the numbered constellation that is nearest to your observed constellation.) Note that generally the Moon is within a 10° band centered on the ecliptic. (The ecliptic is the dashed curve on the Locator.) If you can’t see enough of the night sky to make a match (for example, during daytime observations), simply use the Moon’s observed azimuth/altitude to guess-estimate the Moon’s location in Locator’s date/time-adjusted sky map. Find the numbered constellation that best matches that position.



These observations should be recorded both directly on your drawing and in the Summary Table.

²hand-span $\approx 17^\circ$, fist $\approx 10^\circ$, boy-scout-three $\approx 5^\circ$, pinky $\approx 1^\circ$)

More Rules

Your observations must start before noon 12-Oct-2009. I must receive your completed lab for grading before Thanksgiving break. There is no reason not to start immediately! The total span of your seven observation days should be no shorter than 24 days nor longer than 42 days. Observation days should be at least 3 days apart and no more than 7 days apart³ While not required, students generally find it easier to maintain a fixed observing location and vary the observing time-of-day as little as possible⁴.

All astronomy lab observations are to be recorded in pencil.

Observational anomalies and problems should be recorded in the **Notes:** section. Acknowledge any help you received from classmates in the **Notes:** section. (Unacknowledged help is a form of plagiarism and has similar penalties.)

What to Draw

I've included in Figure 1.1 a sample drawing I made of the Moon.

Your drawing must display the Moon's location (altitude and azimuth) and phase. The horizontal bottom of the drawing's rectangle is to be the mathematical horizon. Mark on this horizon the corresponding azimuthal direction. Feel free to use a digital camera photograph to help you make your drawings (I did). Your drawing is to be scaled to the "handy protractor" that is displayed in each drawing blank. In particular you should be sure that the altitude you report matches what the hand in the drawing would measure. You should include objects (buildings, trees, etc.) that obstruct the mathematical horizon only when they are helpful in locating the Moon. In my example I've included the Abbey Church as the Moon was just a hand-span to the left of the bell banner. (Note: I 'drew'—actually traced from a digital photo—much more architectural detail than you would ever need to include.) While the location of the Moon should be in proportion to the included hand, the size of the Moon must be exaggerated in order to be visible. (My digital photo shows the Moon as approximately the same size as the hexagonal windows of the Abbey Church. If I properly sized the Moon its phase would be very difficult to distinguish.) Up-size the Moon to at least thumbnail size for the hand in the drawing. (The actual Moon is covered by a pinky nail.) The Moon's illuminated parts are white against the black night sky (or in my example by a blue afternoon sky), but since it is hard to show a white Moon on white paper, I've shaded the white part of the Moon black in this drawing. (Another option is to show a black disk with a white bite out of it.) However you decide to display the Moon, you must label with the word "white" the part you mean to be white. Observe and accurately record the orientation of the terminator⁵. *Properly recording this detail will be a significant part of your grade for this exercise!*

³This means the five days of continuous clouds can result in a violation of these rules. If this happens to you, explain what happened in the **Notes** section and record the span of clouded-out days. If I can confirm continuous clouds for those days, there will be no penalty.

⁴Moon rise occurs later each day, so after two or three observations the Moon will be below the horizon at your 'standard' time. Simply wait a few hours until the Moon rises and passes the meridian and use that time as 'standard' for the next few observations.

⁵The terminator is the curve that divides the Moon into light and dark parts.

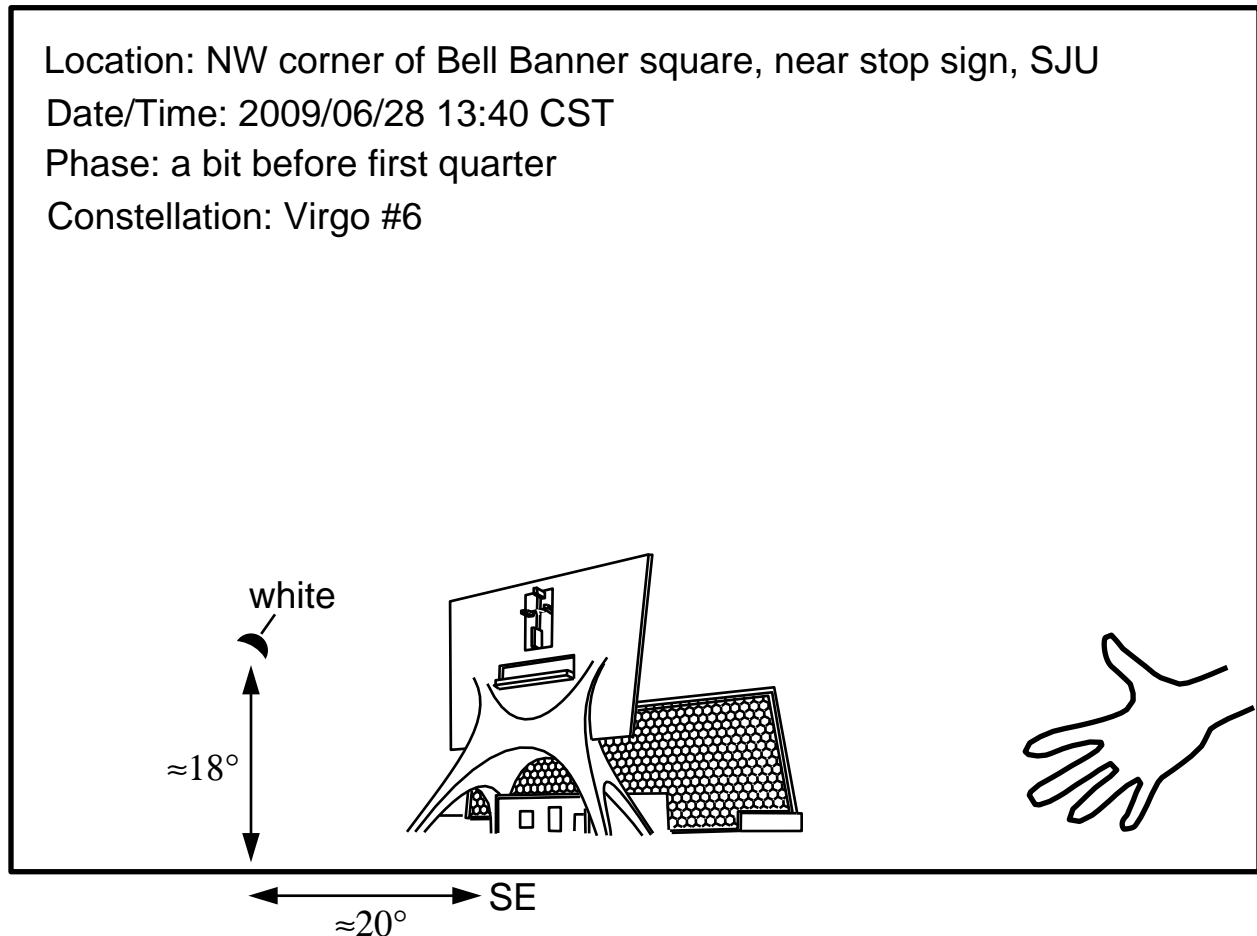


Figure 1.1: I observed the Moon rising behind the Abbey Church at 2:40 P.M. CDT on 28-Jun-09. I made these observations from the NE corner of Bell Banner square, between the stop sign and Music Hall. I actually took pictures with a digital camera in order to make an accurate sketch. Of course I couldn't see any stars when I made these daytime observations, so I set the time/date 1:40 P.M. CST/28-June on my *Star & Planet Locator* and determined the Moon was in Virgo (but not far from Leo). As shown the Moon had an altitude of a bit more than a hand-span. I judged that the azimuth of the Church was SE (but that guess-estimate was based on building orientation not measurement). I could measure that the Moon was about 20° to the left of the Church. My drawing is supposed to show a lunar disk that is a bit less than half illuminated (say 40%), with the terminator oriented about 45° to the vertical. The sky was partly cloudy during these observations. Picking out the small white Moon among the large, moving, bright-white clouds was a challenge. I spent about 20 minutes trying to find the Moon and then accurately record its position.

Observing Instructions

Each day's observations are to be recorded in a drawing and the Summary Table. (I.e., every item listed above under **Rules:** should appear both on your drawing and in the Summary Table.) The first day of observation is a bit special: you are to observe (and record) the Moon at three times with the first and third observations separated by 3 to 5 hours and the second observation at least an hour from the first and third. Make sure to time the start of your observations so that the third observation happens before Moon set⁶! Your aim is to record how far and in which direction the Moon moves. Your drawing for this first day is to be a superposition of the three observations: include in your drawing the location and phase of three Moons, each labeled with the observation time. You must transmit this first drawing to me within three days of the observations. The suggested method is to scan your drawing and attach it as a .gif in an email to me. It is also OK to 'xerox' your drawing, submit it to me by hand, and follow that up with an email to me. In any case, I must receive a *copy of your drawing* and an *email I can reply to* within three days of these first-day observations. I will peruse your drawing, look for misunderstandings of what is required and then follow up with a reply email within three days.

For the other six observation days simply draw/write in the labeled box and transfer the resulting data to the Summary Table.

Calculations

For each of the seven days of observation, mark (with the corresponding numeral: 1–7) the approximate location of the Moon in its orbit around the Earth directly on the chart that is Figure 1.3. Read the figure caption for further instructions.

Plot the Moon's motion around the ecliptic directly on the chart that is Figure 1.2. The lhs y -axis of the plot lists (by Locator number) the constellations of the Zodiac; the rhs y -axis of the plot displays the corresponding the angle along the ecliptic. Note that two full cycles are displayed. Plot your starting lunar positions in the bottom chart, and, as the Moon moves past the vernal equinox, continue on into the top chart. The x -axis records the number of days since the initial observation. For each of your seven observations accurately plot a point showing the constellation and day. Note that constellations really extend several degrees along the ecliptic, and your estimate of the Moons location is inexact. Nevertheless your sequence of positions should show an approximate linear progression. Using a straightedge, draw the line that best approximates your data. Extend that line all the way through the top of the top chart. Based on your line, determine and record the time required for the Moon to make one complete cycle of the ecliptic (i.e., the time required to go through 360° of the chart). Record your results and calculations on the same page as the plot or the adjacent Notes section.

This a good time to check you've written your name on the front cover of this manual!

⁶Many places on the web report Moon rise/set... Google moon rise to find several million.

1abc



2



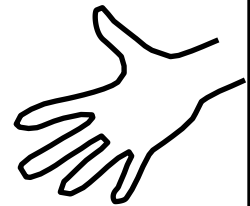
3



4



5



6



7



extra



Notes:

Summary Table:

drawing	Date	Time	Location	Altitude °	Azimuth	Phase %	Constellation #
1a							
1b							
1c							
2							
3							
4							
5							
6							
7							

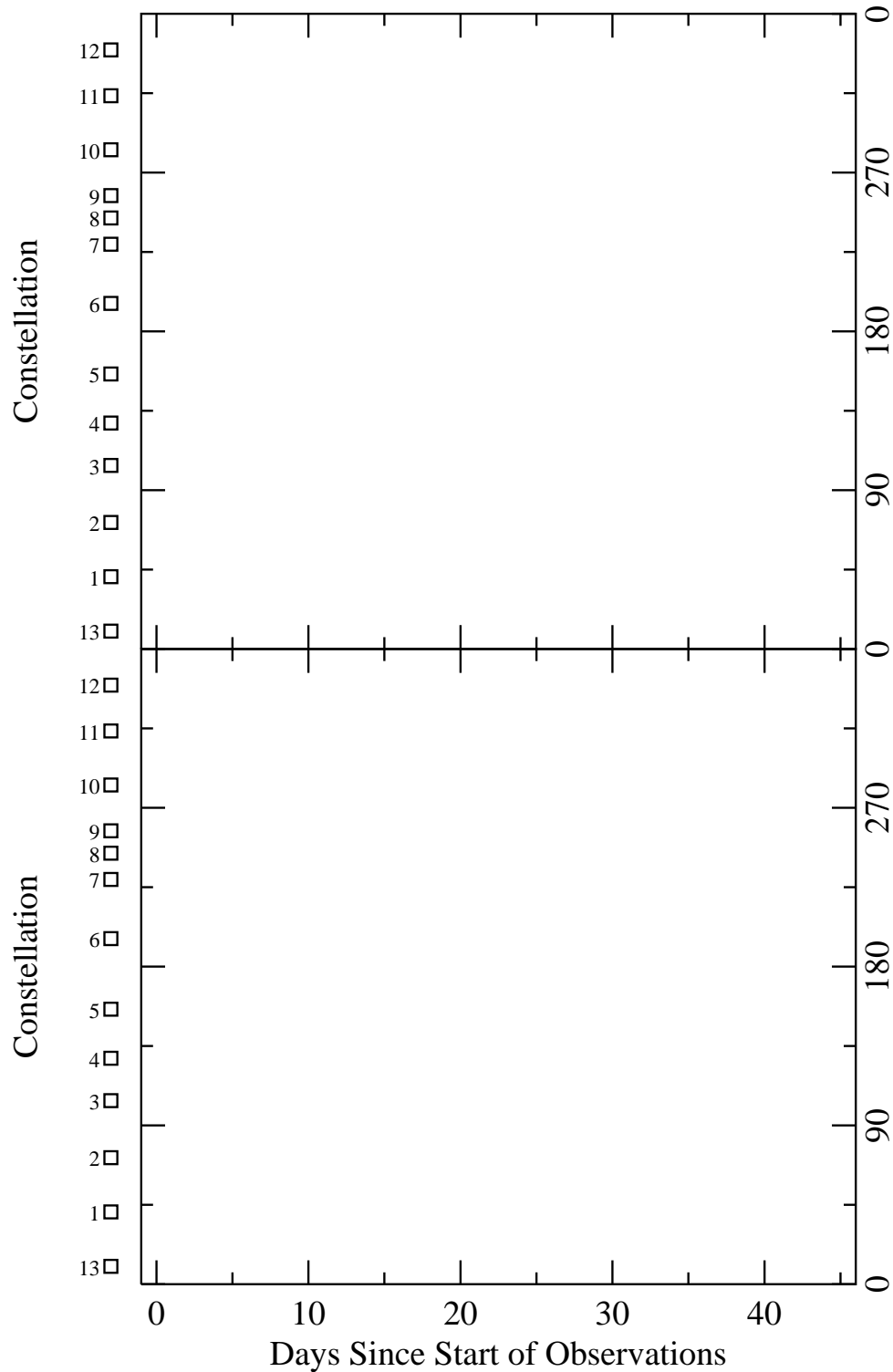


Figure 1.2: Plot your observations of constellation # vs. days directly on this sheet. Use a straight-edge to accurately locate and mark your seven (day,#) observations. Note that the location (angle around the ecliptic) for the center of each numbered constellation is displayed on the rhs, whereas the constellation numbers are recorded on the lhs. Two full cycles are displayed on the y -axis. Start your plotting in the lower chart and, as the Moon passes the vernal equinox, continue on to the top chart. Record the requested calculations on this sheet, including the time required to complete a trip around the ecliptic.

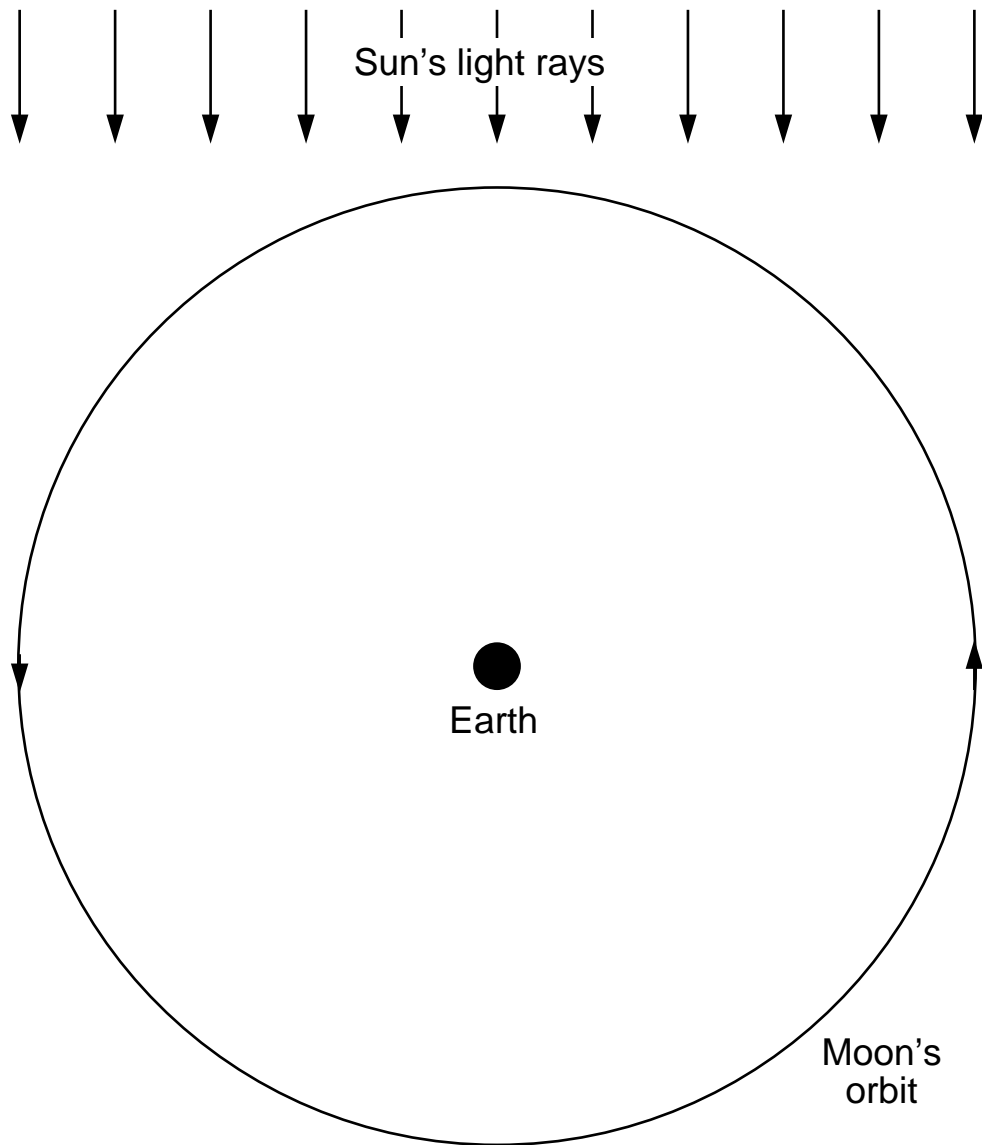


Figure 1.3: This diagram shows a not-to-scale view high above the Earth's north pole. The circle represents the orbit of the Moon; the Moon would move counter-clockwise around this circle. The Earth is the disk at the center of this circle. The Sun is assumed to be far off the the top of this page; the arrows show the nearly parallel light rays coming from the Sun. For each day's observations show where such a Moon must be located in its orbit around the Earth. Directly on this sheet, draw a disk for each Moon. Shade and label the white (illuminated) part of each Moon. (Shade your Moon as it would appear in this diagram from high above the Earth's north pole, not as it appeared from Earth in your observations.) Write an observation label (1-7) adjacent to each Moon.

Home Lab 2: Polar Motions

Introduction

The stars in the sky and the whole celestial sphere seem to rotate about a point that is near the bright star Polaris. If the sky completed a full rotation in exactly 24 hours, the sky at say 9 P.M. would be the same every day of the year. While the rotation period of the Celestial Sphere is nearly 24 hours, in fact it is a bit less. Thus in 24 hours the Celestial Sphere completes a full rotation and a bit more. As a result the sky at 9 P.M. tomorrow will be slightly different from the sky at 9 P.M. tonight. This day-to-day change in the night sky is small; if we let the change accumulate over months it should be noticeable.

Purpose

You will observe the rotation of the stars near Polaris over a few hours and then after two months to see how the pattern has changed.

Prerequisites

This home lab requires you to identify and sketch three circumpolar constellations: Big Dipper, Little Dipper, and Cassiopeia. Many of you will already be able to do this based on previous experience and/or the first week of class. Others may not have the confidence to do this until the first clear lab at the observatory when you will be identifying constellations with my help. Problems may arise if that first lab is cloudy (because you must start these observations before the start of the second lab at the observatory). *If you feel unable to identify and sketch these constellations bring the problem to my attention!* You are responsible to communicate to me your inability to identify these constellations well before the last possible start date (15-Sep-2009).

Rules

You are to make a total of four observations of sky near Polaris on two days separated by at least 2 months. The results are to be recorded in four drawings in the provided drawing blanks. (The first-day observations will be made a few hours apart.) Each observation should include:

1. LOCATION: Where were you when you observed the sky?
2. DATE: Record this in the form yyyy/mm/dd (e.g., 4th of July = 2009/07/04).
3. TIME: Record this in Central Standard Time on a 24 hour clock basis. Your first observations must be completed way before the November ‘fall back’ date, so you subtract one hour from the Central Daylight Time on your watch. Time should be expressed in the form hh:mm. (Again: no A.M. or P.M.: afternoon times simply have 12 hours added, so 1 P.M.=13:00.)

These observations should be recorded both directly on your drawing and in the Summary Table.

More Rules

Your observations must start on or before 15-Sep-2009. Your last observation should be at least eight weeks after your first observation and match the CST of one of your first observations. I must receive your completed lab for grading before Thanksgiving break. If you can locate the required constellations, there is no reason not to start immediately!

All astronomy lab observations are to be recorded in pencil.

Observational anomalies and problems should be recorded in the **Notes:** section. Acknowledge any help you received from classmates in the **Notes:** section. (Unacknowledged help is a form of plagiarism and has similar penalties.)

What to Draw

Your drawing must display the three asterisms: Big Dipper, Little Dipper, and the W of Cassiopeia. Pay particular attention to exactly how they are oriented in the sky (that is what you will be measuring). Your drawing is to be scaled to the “handy protractor” that is displayed in each drawing blank. You should include objects (buildings, trees, etc.) that obstruct the mathematical horizon only if they are helpful in locating low altitude stars. I find it is very helpful to have my SC002 handy as I make these observations and draw the sky.

Observing Instructions

Observations are to be recorded in a drawing and the Summary Table. (I.e., every item listed above under **Rules:** should appear both on your drawing and in the Summary Table.) The first day of observation you are to observe (and record) the circumpolar sky at three times with the first and third observations separated by at least 4 hours and the second observation approximately mid-way between the first and third. Your aim is to record how far and in which direction the sky turns. Make three separate drawings (1a, 1b, 1c) for this first day: one for each time you observed the sky. You must transmit one page (i.e., drawings 1a and 1b) to me within three days of the observations. The suggested method is to scan your drawing and attach it as a .gif in an email to me. It is also OK to ‘xerox’ your drawing, submit it to me by hand, and follow that up with an email to me. In any case, I must receive a *copy of your drawing* and an *email I can reply to* within

three days of these first-day observations. I will peruse your drawing, look for misunderstandings of what is required and then follow up with a reply email within three days.

For the second-day observation (at least two months after the first) select a CST time-of-day that matches a drawing from the first-day observations. Draw the circumpolar sky at that time.

Calculations

For each of the four drawings note the location of the stars: Dubhe (α Ursa Major; the lip of the big spoon), Kochab (β Ursa Minor; the lip of the little spoon), and γ of Cassiopeia (middle of the W). These stars are identified on your SC002. Using a straightedge, draw a line from Polaris to each of these stars. Using a protractor⁷ measure the counter-clockwise angle (0° – 360°) from the downward vertical line shown on each drawing. Record these angles in the Summary Table.

Using the first-day data, plot each star's angle directly on the chart that is Figure 2.1. Note that $1\frac{1}{4}$ cycles are displayed. Plot your starting star positions in the bottom chart, and, if the star moves past the downward vertical, continue on into the top chart. The x -axis records the number of hours since the initial observation. Each star's sequence of positions should show an approximate linear progression. Using a straightedge draw the line for each star that best approximates your three data points for that star. The line's slope ($^\circ$ /hour) indicates the rate of rotation of the star; parallel lines indicate the same rotation rate for all stars. Calculate the slope (rise/run) of the three lines; find the average of those three slopes, which below I call S_{avg} . If the rotation you measured in a few hours continues, how many hours does it take (call that H) to complete a rotation? You need to solve a proportion of the form:

$$S_{avg} = \frac{360^\circ}{H} \quad (2.1)$$

Report your value for H along with the calculations that produced it adjacent to Figure 2.1.

Your answer for H should be approximately 24 hours. If the rotation rate were exactly 24 hours, the star pattern in your second-day observations should exactly match the same-time drawing from the first-day observations. Is that the case? When I did this project I found that my second-day sky had rotated beyond the corresponding first-day sky. Calculate the rate of 'over-rotation' (in $^\circ$ /day) by subtracting the corresponding first-day angle from each star's second-day angle⁸ and dividing by the number of days between the observations. Average your result for the three stars; I call the result below OR_{avg} .

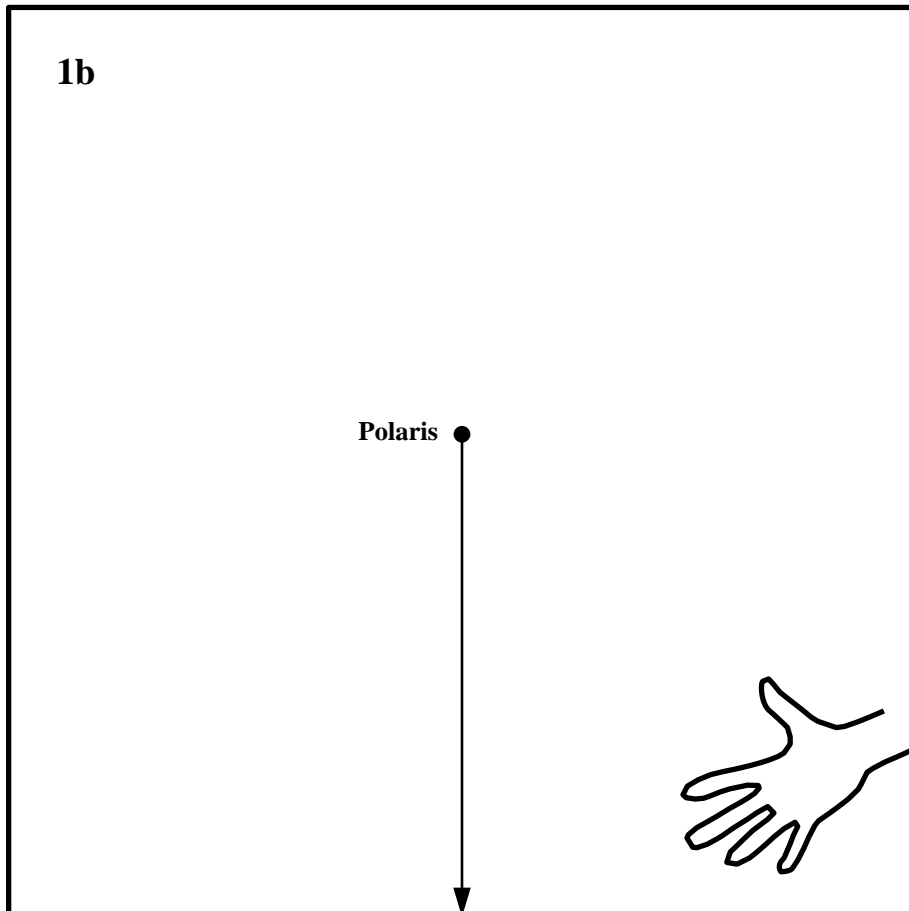
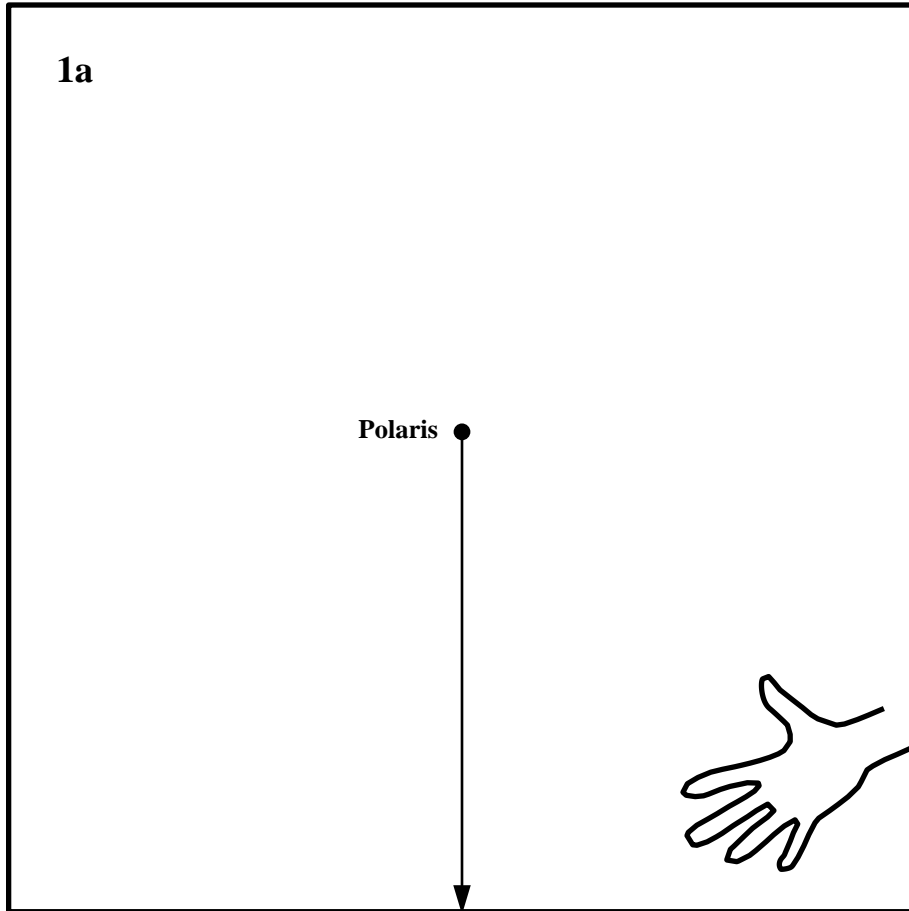
How many days (call it D) are required for this 'over-rotation' to accumulate to one full over rotation? You need to solve the proportion of the form:

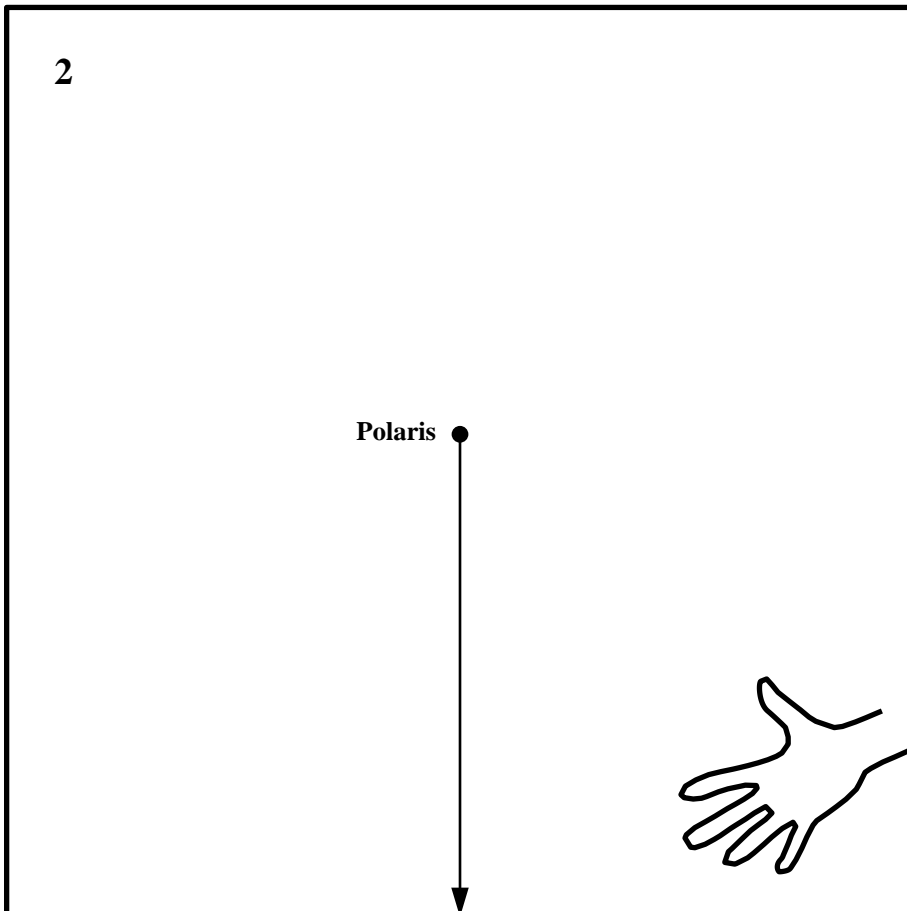
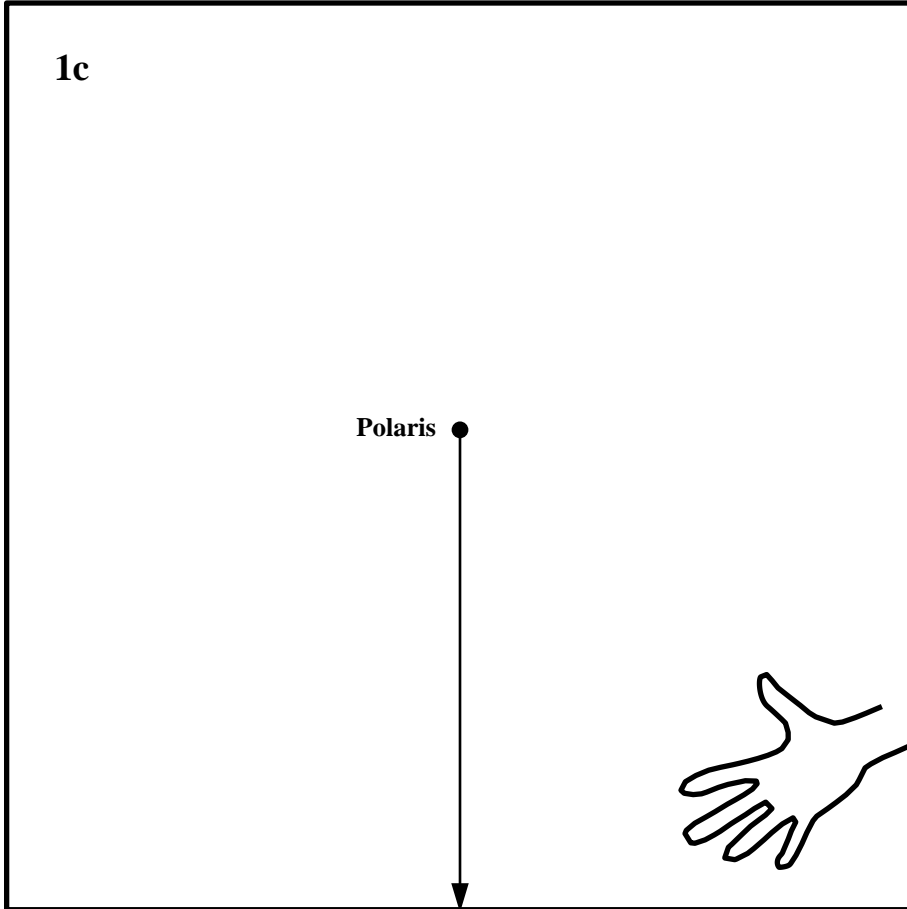
$$OR_{avg} = \frac{360^\circ}{D} \quad (2.2)$$

Report your value for D along with the calculations that produced it.

⁷Feel free to borrow one of the transparent protractors tacked to the bulletin board outside my office.

⁸If the result is negative because the star has passed through the downward vertical compared to the first-day observations, add 360° to the result. Note that the plot does this automatically.





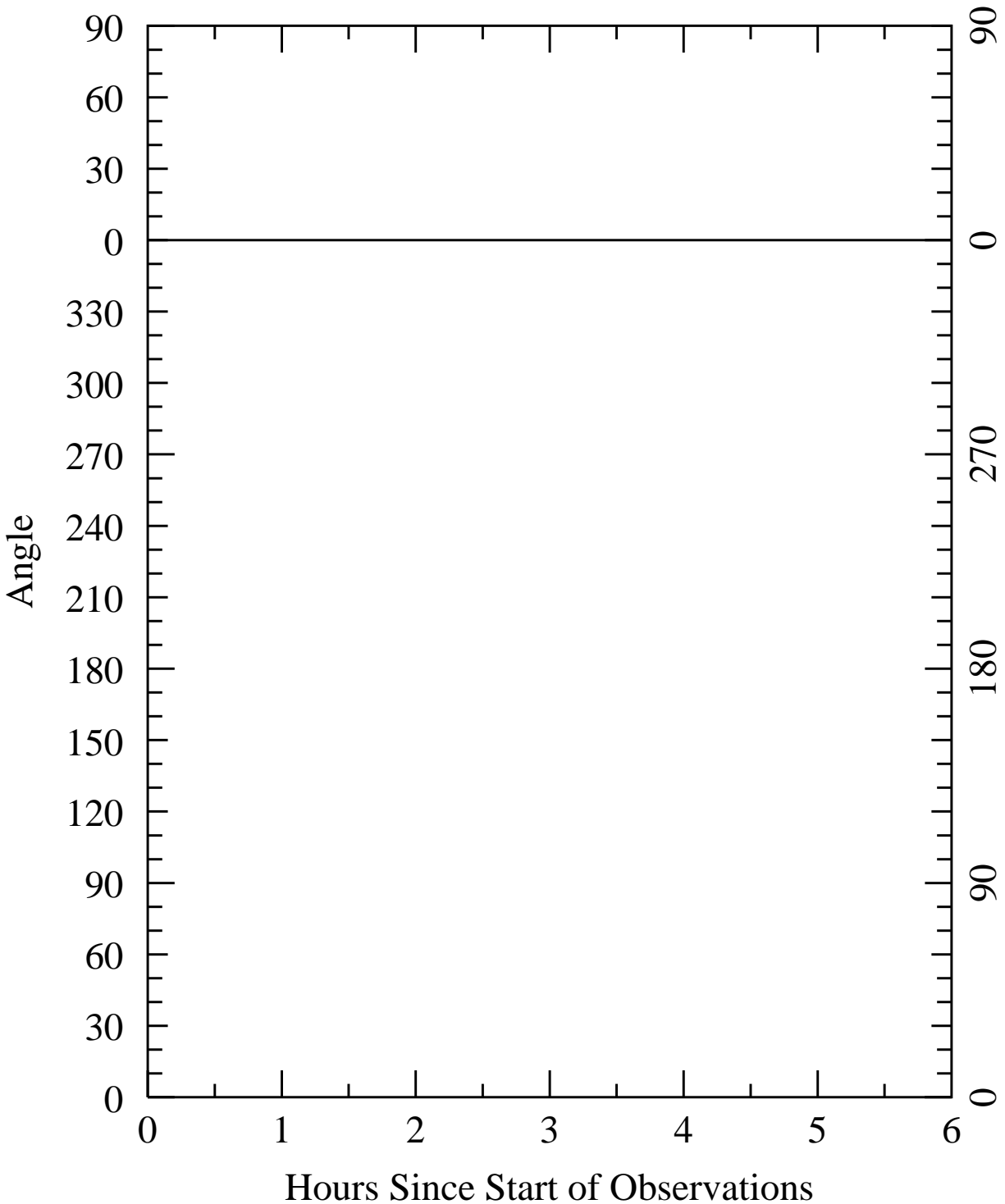


Figure 2.1: Plot your observations of star angle vs. hours directly on this sheet. Use a straightedge to accurately locate and mark your 3 stars \times 3 observations (hour, $^\circ$) points. $1\frac{1}{4}$ cycles are displayed on the y -axis. Start your plotting in the lower chart and, if the star passes through the downward vertical, continue on to the top chart. Draw in the three lines that best approximate the linear progressions. Record the requested calculations on this sheet (or the adjacent **Notes:** section), including the time required to complete one full rotation and the time to over-rotate one full rotation.

Notes:

Summary Table:

drawing	Date	Time	Location	Dubhe ○	Kochab ○	γ Cas ○
1a						
1b						
1c						
2						

Questions

Answer the below questions in the space provided.

1. In your first-day observations: which direction (clockwise or counter-clockwise) did the sky rotate? How fast did it move ($^{\circ}$ /hour)?
2. Do you judge that all three stars had the same rotation rate in the first-day plot? If the rates were in fact not equal what result would you see in the second-day observations?
3. If the circumpolar sky were observed at 10:00 P.M. on adjacent days, how would the positions of the stars on the second day compare to the positions on the first day? Do you think you could actually see this difference?
4. In the first home lab you find that the Moon moved at a different rate from the stars (because it was found in different constellations at different times). Name three other night sky objects that would also have this property of wandering through constellations. How exactly do these wandering stars differ from the usual 'fixed' stars?