Astronomy 50

Lab Manual

Union College

Spring 2015

Professor LaBrake

Astronomy 50 Lab Policies **Spring 2015**
Professor LaBrake

For this course, you are required to complete five labs in three-hour sessions. Since you get Gen-Ed lab credit for AST-050, **the completion of the five labs is a requirement for the course**. For each lab you must show up, fully participate in the lab exercises, and turn in a written report. **Attendance will be taken**. In addition you will be required to attend one observatory open house. The schedule for labs and open houses is posted on the class schedule webpage, with as much notice as possible (since one of the labs is weather-dependent). If you have any conflicts, contact your lab instructor as soon as you know of the conflict (preferably, at least a week before the lab). If you miss a lab because of illness, contact your instructor as soon as you can and bring your instructor a note from the student health service (or whatever doctor or hospital you visited). **Please note that you cannot assume that you can just switch lab sections in a given week because the labs may not occur in parallel and because equipment is limited.**

The main goal of these labs is to teach you about the motions of the sky and several of the techniques by which the dimensions and motions of the Solar System have historically been determined. We'll find the size of and distance to the Moon, and the mass of Jupiter and an extrasolar planet (using Newton's law of gravitation). Weather permitting, there will be an outdoor observing laboratory, in which you will observe the Moon and any other bright planets visible in the evening hours. There will also be evening opportunities to observe using Union's 20-inch telescope on top of the Olin Center. Public open houses at the Observatory are scheduled regularly and will be posted on the class webpage. These events are weather-dependent: if it cloudy, they will be canceled. Check the Union College Observatory homepage for updates. (http://www1.union.edu/wilkinf/observatory/observatory.htm or click on the link from the class homepage.)

E-mail: Evening labs may be canceled, due to weather for example, your lab instructor will send information regarding modifications to the schedule by e-mail, posts on Nexus, or on their website. If you want email sent to an account other than to your Union College account, please inform the instructor as soon as possible. Not receiving email or checking the posted lab schedule is not an excuse for missing lab, and will result in a failing lab grade.

Lab Reports: Each lab will require some written work to be handed in, and each student must hand in their own report. For some labs, only the completion of the appropriate pull-out pages of the lab manual is necessary. Others may require a written report. Follow the instructions in the handouts for each lab.

Academic Honesty: Remember when you write the report, that it must be a reflection of your own knowledge and understanding. *Any report that has identical wording to another will be considered plagiarized*. In addition, if you take any material from of an *internet source*, cite the source. Failure to do so will also be considered plagiarism.

Late Policy: Labs should be turned in by the deadline given at the time of the lab. There will be a 15% reduction in grade per day late and this includes weekends.

Note that Labs (and class activities) will count 20% towards your final course grade.

Astronomy 50, Spring 2015

Name______________________________

Lab 2, Part 1: Phases of the Moon

The Earth and the Sun: Review of Time

1. Make a sketch of the Earth, with light rays from the sun arriving from the left. Imagine that you are viewing the Earth from above, looking down at the North Pole. Show the direction in which the Earth is spinning (counter-clockwise). Indicate where you would be located on the Earth to view sunrise, sunset, noon and midnight.

The Sun, Earth and Moon System: Motion and Phases of the Moon

2. (a) Now make a sketch showing the Moon's orbit around the Earth. Show with arrows the direction in which the Earth is spinning and the Moon is orbiting. The Moon orbits the Earth in the same direction that the Earth spins. Draw a circle representing the Moon at the following places in the orbit: (i) between the Earth and the Sun, (ii), directly opposite the Earth from the Sun, (iii) so that the angle between the Sun and the Earth and the Earth and the Moon is 90 degrees, with the Moon below the Earth, and (iv) so that the angle between the Sun and the Earth and the Earth and the Moon is 90 degrees, with the Moon above the Earth. These locations correspond to the following phases: (i) New Moon, (ii) Full Moon, (iii) First Quarter, and (iv) Third Quarter. **Label each location with the corresponding phase (full name).**

(b) On your sketch in part (a), indicate the lighted portion of the Moon. The view of the lighted portion of the Moon from the Earth determines the phase of the Moon. Note that the Moon has an orbit that is inclined to the orbit of the Earth around the Sun. For this reason, the Moon rarely enters the shadow of the Earth. (When it does, we have a lunar eclipse - see below.)

(c) Sketch what an observer on earth would see for each of the 4 phases in your diagram. Give the time when the Moon rises, when it sets, and the time it is highest in the sky for each phase.

(d) Between the major phases, the Moon wanes (less surface lighted as time advances) or waxes (more surface lighted) as time advances. Over which period of the orbit will the Moon wane? Over which period will it wax?

(e) When the Moon is between a quarter phase and full phase, it is called a "gibbous" moon. When it is between a quarter phase and new moon, it is called a "crescent" moon. On your figure under 2a, label the parts of the orbit that would be called gibbous and the parts that would be called crescent. Label each as "waning" or "waxing".

(f) Sketch the Moon as it might look from the Earth while it is waning gibbous:

The Moon’s Motion Across the Sky

3. The Moon completes an orbit about the Earth once in about 30 days. This means that its position with respect to the stars will vary from day to day. Over the course of an orbit, the Moon will move 360 degrees.

a. How many degrees does the Moon move across the sky per day of its orbit?

b. Since the Moon changes its position with respect to the stars, it will have a different rising time every day. Will the Moon rise earlier or later each day? Justify your conclusion with a sketch: (Hint: use the methods in Questions 1 & 2 to help you answer.)

c. Over the course of a 24-hour day, the Earth rotates 360 degrees. Thus the sky appears to be move at a rate of ___________________ degrees/hour.

d. Given the answers in part (a) and (c), calculate the difference in the rising time of the Moon from day to day:

e. Look up the actual difference in the rising time from day to day (provide the source) and compare your estimate.

The Sun, Earth and Moon System: Eclipses

5. An eclipse of the Moon occurs for rare times when the orbit of the Moon carries it through the shadow of the Earth. What is the phase of the Moon when there is a lunar eclipse?

6. An eclipse of the Sun occurs for rare times when the orbit of the Moon carries it directly in front of the Sun as viewed from Earth. What is the phase of the Moon when there is a solar eclipse?

Lab 3, Part 2: Size of and Distance to the Moon (Instructions)

The diameter and distance of the Moon can be inferred from carefully observing a lunar eclipse. Basically, the idea behind this lab is that since a lunar eclipse occurs because the Moon enters into the Earth's shadow, one can directly see and hence compare the size of the Moon with that of the Earth's shadow. While the Moon is partway into the shadow, you can take a picture, using an ordinary camera and film. The picture that you get will look something like Figure 1 (which is

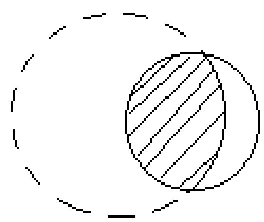

Figure 1

intentionally not drawn to scale--so don't use this figure for your analysis). Using the curvature of the Earth's shadow you can extrapolate to make a complete circle, like the dashed line in Figure 1. Then you can measure the size of the Moon and the size of the Earth's shadow on the scale of the picture; the ratio that you measure on your picture is the same ratio as in reality. Once the relationship between the size of the Earth's shadow and the size of the Earth is determined (tricky!), the actual diameter of the Moon can be easily calculated knowing the actual diameter of the Earth (from your textbook). Finally, knowing the actual size of the Moon, you can find the distance to the Moon by measuring its apparent size.

Historical Perspective

This method of finding the distance to and size of the Moon was used by the Greek astronomer Hipparchus (194-120 BC). Hipparchus is noted as perhaps the greatest Greek observational astronomer. While most of his writings have been lost, his meticulous measurements of Sun, Moon, plnet and star positions over a 30-year period were preserved by Ptolemy in his work, the "Almagest". His result for the distance to the Moon comes close to the modern value.

Procedure

Part 1 – The Diameter of the Moon

There is no lunar eclipse this term, so we will use a photo of a lunar eclipse taken from the web site of an amateur astronomer. Using the picture, first extrapolate the Moon and the shadow of the Earth on the Moon to complete circles. Measure the diameter of the shadow of the Earth, D_{sh} from picture, and measure the diameter of the Moon, D_M from picture. Note that these relative sizes are the same as in reality, so you can calculate their ratio:

$$\frac{\text{actual } D_M}{\text{actual } D_{sh}} = \frac{D_M \text{from picture}}{D_{sh} \text{from picture}} \qquad (1)$$

We know the actual diameter of the Earth is 12,756 km. Once the actual diameter of the Earth is related to the actual diameter of the Earth's shadow, the above measured ratio can be used to find the actual diameter of the Moon. This relationship is given by the equation:

$$D_{sh} + D_M = D_E \qquad (2)$$

The derivation of this equation is completely described in the Appendix at the end of this section of the lab manual. Once you measure the diameters from the picture and calculate the ratio above, use these two equations to solve for the diameter of the Moon, D_M. Note – this last step requires a bit of algebra. Ask for help from your instructor or another student if you get stuck.

Part 2 – The Distance to the Moon

The distance to the Moon can be inferred from the diameter of the Moon. Recall from lecture that the actual size of an object is related to its angular size and its distance. That is, the diameter of the Moon, D_M, and the distance of the Moon, d_M, are related to the angular size of the Moon, q_M, by

$$\theta_M \text{ (in radians)} = \frac{D_M}{d_M}. \qquad (3)$$

Therefore we just need to measure the Moon's angular size to determine its distance.

The angular size of the Moon is ~½ degree. If the Moon is visible during the lab period, we may make this measurement outside. See next part for explanation. Otherwise substitute ½ degree for the angular size of the Moon, Θ_M, into Equation (3) along with your measured value for the diameter of the Moon, D_M, and solve for d_M to obtain the distance to the Moon.

To measure the Moon's angular size:

We can make a measurement of the angular size of the Moon using a "cross-staff". Imagine holding up a ruler to the sky at arm's length (say about 70 cm) and measuring the apparent distance between two objects. Suppose you measured the apparent distance to be 2 cm. What you found is that the angular separation between the two objects is the same as that of the 2 cm markings on the ruler held at a distance of 70 cm. Since you know the actual size and distance of the latter, the angle, given by the small angle approximation, is q (in radians) ~ 2 cm/70 cm. A more accurate "cross-staff" consists a ruler tacked to the end of a stick of fixed length, which is held up to one's eye. The measured angular size of the Moon is then

$$\theta_M \text{ (in radians)} = \frac{\text{size of Moon as measured on ruler}}{\text{length of stick}}. \qquad (4)$$

If the Moon is visible during the lab period, measure your own value of the angular size, and use in Equation (3).

To Hand In:

- Completed Part 1 worksheet.
- Eclipse photo with your estimated circles and diameters labeled.
- Clear calculation sheet showing determination of diameter and distance, with brief explanations of calculations included.
- Completed Part 2 Question Sheet

Lab 3, Part 2: Size of and Distance to the Moon (Questions) AST-050

Name ___________________________

Answer each of the following questions by writing your answer neatly. Alternatively you may attach a typewritten sheet answering each question.

1. Look up the actual diameters of the Moon and Earth and the distance of the Moon and give your source (s).

Diameter (Moon) = ________________________ Source(s):

Diameter (Earth) = ________________________

Distance (Moon from Earth) = ______________________

How does this compare to the diameter and distance that you measured? What do you think is the major source of any discrepancy? Be specific; do not use phrases such as “human error.”

2. Find the value that Hipparchus measured for the ratio of the Moon to shadow (or Moon to Earth). Compare to your own value and the actual value. (Cite your source for Hipparchus's value.)

3. The Moon's orbit is actually elliptical. How will this influence the diameter of the Moon that is measured during a lunar eclipse? Look up the range in angular sizes of the Moon over its orbit and recalculate the distance of the Moon for the minimum and maximum values to see how big an effect this would be.

5. The angular size of the Sun as viewed from Earth is also about ½ degree. Why does this make a total solar eclipse possible?

6. What is meant by an annular eclipse? Explain why this happens.

7. Briefly summarize why the measurement of the Moon's diameter and therefore distance, as well as the measurement of other physical properties were so important in the history of astronomy.

Appendix: Geometry of Lunar Eclipse Measurements

Here we are concerned with figuring out the relation between the size of the Earth's shadow and the size of the Earth. Let's start by considering the geometry of a lunar eclipse. The situation, as seen from the North Pole, is depicted in Figure 2 below. Note that the Earth's shadow is really a cone in space. It comes to a point because the Sun is so much bigger than the Earth. The Moon orbits the Earth at a distance of d_M.

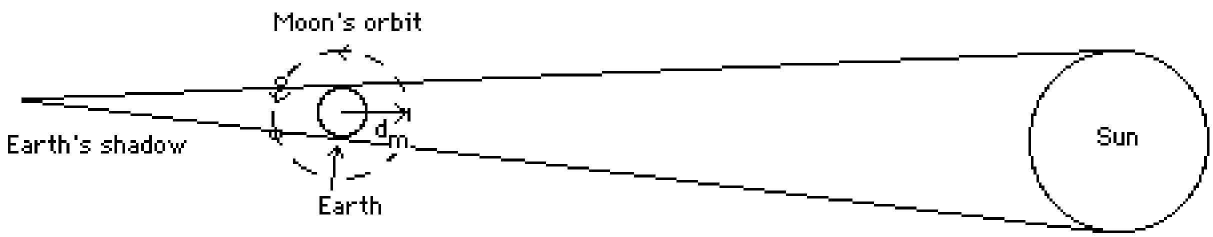

Figure 2

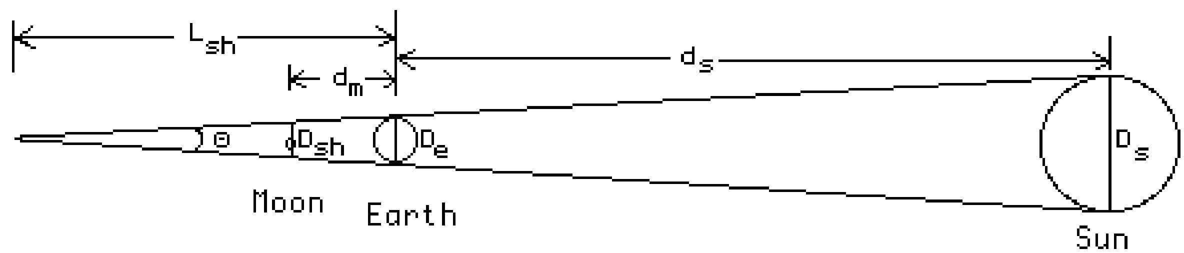

Figure 3

Now consider Figure 3, which is similar to Figure 2 but with some distances and lengths labeled with variables. The only variables you need to follow are θ, D_S, D_E, d_S, and L_{sh}. θ is the angle that the Sun's rays meet at the end of the shadow, D_S is the diameter of the Sun, D_E is the diameter of the Earth, d_S is the distance of the Sun, and L_{sh} is the length of the Earth's shadow. Note that θ is also the angular size of the Earth as seen from the end of the Earth's shadow. Consider the relative sizes of the Sun and the Earth. Since the Sun's diameter is so much much larger, the distance from the Earth to the end of the shadow is a tiny fraction of the distance from the Sun to the end of the shadow. Therefore, the distance from the Sun to the end of the shadow is essentially the same as the distance of the Sun from the Earth (these distances differ by only 1%). Think about what this means--that the angle θ is essentially the same as the angular size of the Sun as seen from the Earth. And, since we get such beautiful solar eclipses we also know that the angular size of the Sun must equal the angular size of the Moon. Therefore, the angle θ also equals the angular size of the Moon. This is extremely convenient, for then we can draw Figure 4, below.

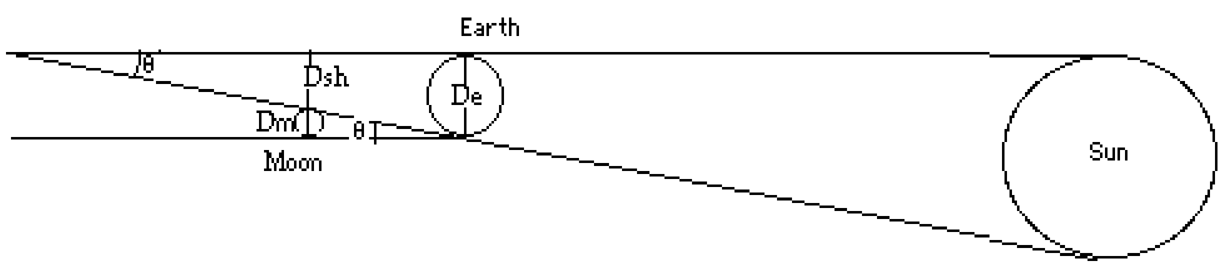

Figure 4

In Figure 4, the Moon is at the edge of the Earth's shadow, as if this were a snapshot of Figure 2 taken at the time the Moon has just left the Earth's shadow. Additionally, another line is added--the line on the bottom going from the edge of the Earth to the edge of the Moon (and beyond). Now note that we have two lines going from the lower edge of the Earth to either side of the Moon: one is the lower edge of the Earth's shadow and the other is the line that has been added. What we have, then, is a representation of the angular size of the Moon as seen from the Earth (when the Moon is on the horizon). Now recall that the angular size of the moon equals the angular size of the Sun, which equals angle θ, the vertex angle of the Earth's shadow. The fact that these two angles are equal, by the geometrical law of "alternate interior angle", means that in Figure 4, the top and bottom lines extending from the edge of the Earth to the left must be parallel. Therefore, the perpendicular distance between these two lines at any two points will be equal. And now for the final point: this means that the distance between these two lines at the position of the Moon is equal to the distance between the two lines at the Earth. This means that D_{sh} plus D_M equals D_E, the diameter of the Earth. That is, $D_{sh} + D_M = D_E$.