ASTRONOMY 414 – Spring 2012

Astronomical Techniques

Instructors

Ed Sutton (ecsutton@illinois.edu).
My office is room 129 Astronomy, and my office phone number is 333-9339.
I generally will be available in my office during normal hours with the following exceptions:
   3:30 – 5:00 PM Tuesday (Astronomy colloquium plus any special colloquia)
   3:30 – 4:30 PM Wednesday (Physics colloquium)
   1:30 – 3:00 PM Thursday (mentoring at Jefferson Middle School)

TA: Dominique Segura-Cox
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   132 Astronomy, 244-5469.

Class Times

Monday, Wednesday, and Friday 10–11 AM in room 134 Astronomy
Laboratory work: to be scheduled

Grading

Normal letter grades (including +/-) based on:

   20% Homework assignments
   20% Observing projects
   20% Midterm (tentatively March 2, in class)
   40% Final (May 8, 8:00–11:00 AM)

Textbooks

There is no required textbook. In principle, you should be able to get by using the notes I supply, either printed or on-line. There are 4 recommended texts:
The book by Bradt is a little outdated, but generally adequate. I like the pamphlet by Lyons very much, and it is small and inexpensive ($30.95 new from Amazon). There is no need to purchase the McLean book; full online access to McLean is available to you through the University Library. The book which I wrote has a list price of $75. As I write this, it is available from Amazon for $69.56. I understand that it will be available direct from Cambridge Univ. Press for $60 (plus shipping) through 10/1/12 using the discount code SUTTON12. An eBook version will be available at some point.

Course Content

The traditional content of this course includes:

- Time scales, coordinate systems & transformations
- Data reduction & error analysis
- General properties of radiation, detection systems
- Optics & optical telescopes
- Optical & infrared imaging, photometry, and spectroscopy
- Radio telescopes
- Radio interferometry and spectroscopy.

This semester I intend to open this up a bit and discuss other wavelength bands and observations of other than electromagnetic radiation.
This semester you will work together on several observational projects:
  Sextant Observations of a Solar Transit (due 3/30/12)
  Parameters of the Moon’s Orbit (due 4/13/12)
  Observations of Satellites of Saturn (due 4/27/12)

For these three projects written reports are required. A complete report consists of at least
the following basic elements:

1. All “raw data” sheets (i.e. everything that was recorded during your observations).
   This should always include unambiguous statements of date, time, and place.

2. A description of the procedures used and the reasons for these procedures. In particular,
   it is important for you to describe any departures from or elaborations on what
   is supplied in the writeup.

3. Error estimates for all observed quantities.

4. Any required calculations, graphs, or conclusions.

5. Calculations describing the propagation of errors and a statement of the final uncertainties in your derived results.

Sextant Observations of a Solar Transit

(Observe before 3/7/12; Report due 3/30/12)

Purpose: To determine your latitude and longitude by using a sextant to observe a meridian
transit of the Sun. In this project you will make a series of accurately timed measurements of
the Sun’s altitude. The maximum altitude observed will be used to determine your latitude.
The time at which the Sun crosses the meridian will be used to determine your longitude.

Preparation: Before the day of the experiment, read the instruction manuals to become
familiar with the sextant and the artificial horizon. Decide whether you will make an upper
or lower limb observation or one of the center of the Sun. Make a few practice measurements.
Learn to take fast, accurate readings, as you will need to work rapidly during the actual
observations. Select a suitable point for your observations, somewhere with a clear view to
the south (southeast through southwest).
Observations:

1. Set your watch to the time signal from a WWV radio, a GPS receiver, a self-setting radio “atomic clock”, or from http://nist.time.gov (click either on Central Time or on the tab labelled UTC; you will need to convert to UTC eventually). Record any remaining offset between your watch time and UTC to the nearest second.

2. Set up the artificial horizon. A drop of light oil will help smooth the surface of the water. I recommend using the orange and blue plastic shades.

3. Select the proper combination of horizon and index shades to provide adequate eye protection for both beams. Dim the Sun’s images enough so that you can observe them comfortably. It helps if they are of similar brightnesses.

4. Adjust your sextant and record its index correction.

5. Begin making measurements at least 1 hour before local noon. Make a measurement every few minutes and continue until at least 1 hour after local noon. If you work in pairs, the person holding the sextant can say “MARK” the instant he has an accurate fix on the Sun. The second person can record the exact time, along with the angle which the first person then reads off his sextant. Switch roles every 2 or 3 readings.

Reduction:

1. Plot your data in terms of sextant reading versus your watch time. Fit the data to obtain the maximum altitude and the time of local apparent noon.

2. Correct the altitude for the index correction of the sextant and for atmospheric refraction. If you did upper or lower limb observations, look up the semidiameter of the Sun in the Astronomical Almanac and correct for that as well. Look up the Sun’s declination at the time of your observations. Use these values to calculate your latitude.

3. Convert your watch value for local apparent noon to UTC. Look up the equation of time and/or the right ascension of the Sun. Use this information to calculate your longitude.

4. Consider the uncertainties in your measurements and how these affect your final answer.

5. Compare these results with the true latitude and longitude of Champaign/Urbana.

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1. If you use the colored plastic pieces on the artificial horizon, you may not need additional filtering with the horizon shades. However, you will need at least the square blue index shade, possibly both index shades.
Parameters of the Moon’s Orbit

(Report due 4/13/12)

Purpose: To determine a number of parameters relating to the orbit of the Moon. This exercise consists of two parts. In the first part you will make a series of observations of lunar position, spread over at least one month. From these you will determine the orbital period, the inclination of the lunar orbit to the ecliptic, and the longitude of the ascending node. In the second part you will study variations in the geocentric distance, the apparent diameter, and the orbital rate of the Moon.

Part 1: At night go outdoors and observe the position of the Moon. Record the date, time, an estimate of the phase, and estimates of either the hour-angle/declination or the altitude/azimuth. Note the position of any nearby bright stars. Calculate the position of the moon in right-ascension/declination and plot it on any good star chart such as astro4.ast.vill.edu/labs/sc1h.jpg observe.phy.sfasu.edu/SFAStarCharts/SFAStarChartsAll.pdf.

Repeat every night for the next month, weather permitting. If necessary, continue your observations into the next month to fill in any large gaps.

a) From your observations, calculate the ecliptic longitude of the ascending node of the orbit. Estimate the uncertainty in this quantity.

b) Calculate the inclination of the lunar orbit to the plane of the ecliptic. Estimate the errors.

c) Calculate the orbital period and estimate errors. If measured from fixed ra to fixed ra, this is known as a sidereal month.

Part 2: In this part, you will measure the apparent diameter of the moon and its orbital rate and relate these quantities to the lunar geocentric distance.

a) Within a few days around 1/30/12, 2/27/12, or 3/26/12 measure the diameter of the moon using the technique described on the attached sheet. Measure the diameter again around 2/11/12, 3/10/12 or 4/7/12. What is the significance of these dates?

b) On these same nights measure the rate at which the moon moves through the field of background stars, using the technique described below. Interpret your result using Kepler’s second law.
c) On these same nights record the position of the moon using the telescope’s setting circles. Set the moon in the center of the field of view. Record the UT, the declination, hour angle, and sidereal time. Convert the latter to right ascension. Compare with right ascension and declination interpolated from the Astronomical Almanac. Is there an observable difference?

d) Relate the quantities determined in a) and b) to the geocentric distance of the moon. Which quantity provides a better means of estimating this distance? See if you can estimate how your results would change if you utilized topocentric coordinates.

A Technique for Measuring Lunar Diameter: The apparent lunar diameter can be measured from the size of the image formed by the twelve inch refractor. Prepare a template consisting of a sheet of thin white paper on which you have drawn a variety of concentric circles of known diameter. Remove the eyepiece holder from the telescope. Tape your template to the tailpiece of the telescope. Focus the tailpiece and determine the size of the circle which best fits the outline of the lunar disk. If this proves difficult, hold the template a few inches behind the tailpiece and view the image from the other side.

An alternate low-technology approach which should work quite well is the classic pinhole camera. Prepare a large opaque sheet of cardboard with a small hole. Hold this a fixed well-known distance away from another sheet on which the image is to be projected. The ratio of the size of the projected image to the separation will give the angular size of the moon. Your pinhole should be much smaller than the projected image, just large enough to let sufficient light through.

A Technique for Measuring the Orbital Rate of the Moon: Find the moon in the 12 inch refractor. The earth’s rotation causes stars to move through the sky at the sidereal rate of 15″ cos δ per second of time. Turn on the tracking motor of the telescope to match this motion (i.e. the stars will appear stationary in the telescope). Determine in which direction the moon appears to be drifting by observing its displacement on the template you used above. Make two precisely separated marks on this (or another) template and determine the time it takes the limb of the moon to move from one to another. If you are patient, you can wait and let the moon drift across its entire diameter – this will take about one hour. It may be desirable to do this with the wide field eyepiece and project the full image of the moon onto a large projection screen. Your result will be somewhat complicated by the effects of parallax (your observing point is displaced from the center of the earth).
Observations of Satellites of Saturn

(Report due 4/27/12)

We will use Hubble Space Telescope data on a set of small Saturnian satellites (Enceladus, Epimetheus, Helene, Janus, Mimas, Pandora, Prometheus, and Tethys) to calculate the mass of Saturn. Each student will be assigned a unique pair of satellites. You are free to consult with any student with whom you share a satellite. The Hubble Space Telescope data will give position offsets from the center of Saturn in terms of \( \cos \delta \Delta \alpha \) and \( \Delta \delta \), in units of arcseconds, and the corresponding measurement uncertainties.

To acquire your data, go to

http://pds-rings.seti.org/volumes/ASTROM_0001/DATA/EASYDATA/.

Obviously a lot of the work has been done already. Someone has looked at the HST CCD images from the WFPC2 instrument, has located centers of the planet and the satellites, has oriented the image with respect to the RA-DEC coordinate system, has determined the “plate scale” (the pixel spacing in arcseconds), and has calculated offsets and uncertainties.

Your job is to convert these data into orbital parameters, to make 2 determinations of the mass of Saturn, and to combine the two measurements into one overall measure of the mass of Saturn with an associated uncertainty.

First: select which of the data you are going to use. These satellites have orbital periods of between 0.5 and 3 days, so you would like to find a stretch of data of about that length. If you try to combine data separated by more than a month or two, you will run into two problems: 1) losing track of what orbit you are on, 2) the Earth-Saturn distance will be changing too much, making the angular size of the orbit change. Consult with me if you have trouble deciding which data to use.

I am not going to specify a particular method for analyzing the data. It will be much more valuable for you to explore possibilities and decide on what you believe to be the best approach.

1. You are free to make some simplifying assumptions, as necessary, as long as you retain enough information to do the job.

2. You may look up the distance between Earth and Saturn for the particular observations you are studying. The normal place to look would be the Astronomical Almanac for the appropriate year (pages E30-E33). But there is also a Web tool at www.fourmilab.ch/solar/help/timedate.html. [Put in the time and date you want,
push the appropriate button, then "update". Planetary distances will appear at the bottom of the page. It seems to be accurate.]

3. There may be some data reduction packages available that will give you an answer with relatively little work. Using one and getting an accurate answer is much less valuable, and will receive much less credit, than working through the problem on your own but getting a less accurate answer. I suggest starting just by plotting your data. This is not to say that you cannot use any software. You can certainly use graphical software and you may, at some point, wish to use a least-squares fitting routine. These are readily available on some hand calculators and any PC.

4. List the simplifying assumptions that you have made, so that I know that they were deliberate, conscious decisions.

<table>
<thead>
<tr>
<th>Name</th>
<th>Satellites</th>
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<tbody>
<tr>
<td>Arteaga</td>
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